REMOTE SENSING SYSTEMS OPTIMIZATION
FOR GEOBASE ENHANCEMENT

THESIS

Steve J. Paylor, Captain, USAF

AFIT/GEE/ENV/03-20

DEPARTMENT OF THE AIR FORCE
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Steve Paylor

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Abstract

The U.S. Air Force is in the process of implementing GeoBase, a geographic information system (GIS), throughout its worldwide installations. Air Force GIS needs can be augmented by imagery from aerial and satellite platforms. Imagery has greatly improved over the past several years and provides high resolution coverage of features on earth. Various imagery types will significantly increase GeoBase usefulness in a range of mission requirements. Potential Air Force uses of imagery include identifying heat loss, environmental monitoring, command decision-making, and emergency response.

The research develops a decision tool to determine the appropriate imagery for a given Air Force Application. Current literature identified proven imagery applications. Literature review and a 2002 Air Force Geo-Integration Office (AF/GIO) survey were used to develop a comprehensive imagery applications list that satisfies Air Force mission requirements. An imagery decision matrix was crafted that allows a user to select an application and see imagery that fulfills the requirements for the task. An imagery system key provides further details of each imagery type.

The matrix was tested at three Air Force bases. Increased awareness of the possibilities of an imagery-enriched GeoBase, and the efficiency afforded by the matrix, greatly reduces the time to identify and implement imagery. Available imagery was identified for the three Air Force bases at the National Imagery and Mapping Agency (NIMA) through a government contract at no additional cost. Current IKONOS imagery of Elmendorf Air Force base was obtained for analysis and implementation into GeoBase.

REMOTE SENSING SYSTEMS OPTIMIZATION FOR GEOBASE ENHANCEMENT

I. Introduction

1.0 Background

"GeoBase is an initiative to change how geo-spatial information resources are being acquired, implemented, exploited, and sustained on USAF installations around the world" (www.geobase.org, 2001). Geo-spatial information consists of natural and manmade features with geographic coordinates. Some examples of geo-spatial information include a building, road, pipeline, lake, forest, and wetland identified according to a reference system. With a single reference system in place, these features are analyzed with respect to one another. Squadrons such as civil engineering, security forces, and communications use this geo-spatial database to make more informed decisions.

The GeoBase program is focused on providing a Common Installation Picture (CIP) for all users on a given Air Force base. A CIP involves all organizations of a base using one shared map, instead of each unit developing its own map. Personnel from different units coordinate efforts to contribute details for one base map. This concept is new because previously each organization developed its own map. A CIP improves efficiency by preventing personnel from going through the costly and time-consuming process of creating individual maps. The result of this unified effort is a more consistent and comprehensive map product.

The CIP is comprised of several types of data including images. At the heart of the CIP is an image of the geographic area under consideration. Presently, the images most often used are 1-meter black and white panchromatic aerial photography (Cullis, 2002). According to Lillesand and Kiefer, panchromatic film is sensitive to light in the visible spectrum from 0.3 μm to 0.5 μm, representative of the human eye (1994:77). Photography is widely available for most geographic areas and relatively inexpensive.

The core computer system that enables GeoBase users to manage geo-spatial data is a Geographic Information System (GIS). A GIS is a computer database that contains geo-spatial information. It is the principal tool used to input, view, and manipulate data about a specific location or earth feature. This database of information is often casually referred to as a map. Many layers of data can be viewed simultaneously in order to make a more informed decision about a specific location or land feature. For example, an image such as a panchromatic photograph taken from an airplane could be one layer of data in a GIS. Additional layers may include computer-aided drawings (CAD) of buildings, streets and utilities; special use or restricted zoning data; soil types by geographic area; and elevation data. GeoBase may improve DoD decision-making in a variety of arenas. It has the potential to support missions related to environmental management, disaster response, homeland defense, land-use planning, sustainable development, infrastructure management, and many other Air Force requirements. The GeoBase concept involves many users with the ability to access and update information on a geo-referenced relational database.

The GeoBase concept, when used as part of a deployment, is known as GeoReach. GeoReach database requirements are similar to those for GeoBase, with

additional contingency requirements. This research may be applied to GeoReach when additional contingency requirements are taken into account.

The current status of GeoBase varies and depends on the mission and leadership priorities of a particular base as well as the training and competency of the GeoBase users. The Air Force Geo-Integration Office (AF/GIO) is responsible for assisting bases in setting up their GeoBase function. Additionally, each major command (MAJCOM) has a Geo-Integration Officer in charge of overseeing the development of GeoBase programs in their MAJCOM. Some Air Force bases have functional GeoBase capability, while others have only begun the process of setting up an operational GeoBase. Because the Air Force is in the early stages of GeoBase implementation, base personnel will benefit from research that provides guidance in the selection of imagery most suitable to GeoBase.

Images of Earth features and resources are gathered by remote sensing techniques. Remote sensing is the process of obtaining information about a geographic area from a distant location using photographic and non-photographic methods. Photographs produce images with a chemical reaction on light-sensitive film. Non-photographic images, also referred to as digital images, are produced by electronic signals. Lillesand and Kiefer make a key distinction, "Because the term image relates to any pictorial product, all photographs are images. Not all images, however, are photographs" (1994:23). Remote sensing equipment can be attached to different types of platforms, such as a building, light pole, airplane, helicopter, or satellite. The most common method of obtaining remote sensing data is through aerial (airplane or helicopter) or satellite platforms. These platforms provide broad coverage of the Earth's resources, providing imagery that is

valuable to many users. A platform may be equipped with either photographic or digital imaging equipment. Once these images are produced, a GIS is used to compile and analyze them. Data from several sources is used to obtain information about features in the GIS.

There is a wide range of remote sensing images that have been collected since the 1970s. The available imagery includes black and white panchromatic, black and white infrared, color, color infrared, multi-spectral, radar, thermal, and light detection and ranging (LIDAR) images. Remote sensing images span the energy spectrum consisting of ultraviolet (UV) light, visible, infrared, thermal, radar and passive microwave wavelengths (Lillesand and Kiefer, 1994:11). With the exception of the visible portion of the spectrum, remote sensing images are able to detect distinctive segments of the electromagnetic energy spectrum beyond the capability of the human eye. Aerial and satellite remote sensing platforms collect imagery on a scale covering large areas of land.

Resolution, cost, and availability of imagery are some of the limitations that must be taken into account when determining which types of imagery to incorporate into GeoBase. Spatial resolution may provide detail to the centimeter with newer aerial remote sensors. Older archived imagery provides a useful foundation of data until higher resolution imagery becomes available. Images may be supplied at minimal cost, in some instances, through government agencies such as the National Imagery and Mapping Agency (NIMA), or images can be purchased from several commercial sources. The availability of images is a limiting factor, since imagery is not captured for all areas of the earth at all times. A common satellite platform, Landsat, typically passes over the same geographic location once every two weeks. Because it captures images optically,

poor weather in the geographic location of interest may prevent a clear image of features on the ground (Lillesand and Kiefer, 1994:431). Newer satellite platforms such as IKONOS and Quickbird pass over the same geographic area every few days. An archive of imagery for a specific geographic location over several months or years may be required to gather necessary information for a project. These factors will guide the selection of appropriate imagery to use when constructing a GeoBase database.

1.1 Problem Statement and Context

The Air Force needs to identify what type of remote sensing imagery will optimize GeoBase capability to meet mission requirements. The Air Force is in the early stages of GeoBase implementation throughout its bases. Each base has a unique set of factors to take into account. Ideally, each base will consider its opportunities and constraints before proceeding with the implementation of GeoBase. This research will enable bases in the planning phase, and bases choosing to update data in their GeoBase, to select the best possible remote sensing images to support mission requirements.

1.2 Research Objectives

Develop a decision analysis tool for evaluating the use of remote sensing imagery types for specific Air Force applications. Provide a decision analysis methodology and research matrix to the Air Force for use in future evaluations of remote sensing imagery.

1.3 Methodology

The research methodology involves a five-step process. The researcher gained GeoBase and GIS expertise, developed a GeoBase potential-use template (Air Force Applications List), researched remote sensing imagery, developed a decision analysis

tool, validated the decision analysis tool, and procured imagery from a government agency. GeoBase and GIS expertise was gained from literature review and laboratory training on GIS Internet tutorials. A GeoBase potential-use template for a generic base was developed from an AF/GIO study and base mission information. Current remote sensing imagery was researched to explore applications, limits and cost of imagery. A decision analysis tool was developed to evaluate remote sensing alternatives for Air Force requirements. Three Air Force Base GIOs validated the decision analysis tool, and the researcher validated imagery procurement.

1.4 Relevance

GeoBase has the potential to revolutionize the use of geospatial information in Air Force decision-making to the extent that the Internet has made information available to each person on a desktop computer. Expanding the capability of GeoBase with varied imagery types to solve multifaceted problems has a direct impact on mission accomplishment. This thesis will help to refine GeoBase as a tool essential in meeting diverse Air Force requirements. The decision analysis tool used in this thesis provides clear identification of which imagery is the most useful and cost effective to aid in a problem-solving strategy. This research will promote a more compatible and free-flowing information exchange among GeoBase users and facilitate greater efficiency and familiarity with GeoBase. This thesis provides direction to Air Force GeoBase system administrators when developing their GeoBase programs and empowers Air Force leaders to make more informed decisions.

1.5 Thesis Overview

The thesis covers literature review in Chapter 2. Archived and current imagery capabilities are reviewed and remote sensing applications are identified. Chapter 3 outlines the methodology of this research. Decision analysis methods are explained and parameters of this research effort are discussed. Chapter 4 provides the results and analysis of the thesis effort. Chapter 5 provides results, a summary of the work, limitations of the thesis, and recommendations for future research.

II. Literature Review

2.0 Introduction

This literature review describes the current status of GeoBase and remote sensing imagery. Remote sensing produces visual information products such as photographs, which are then used in GeoBase for analysis. The geo-spatial database that comprises GeoBase technology displays the geographic location of natural and manmade features according to a common reference system. A reference system shows the relative position of features with respect to latitude, longitude, and elevation. In a GIS, this is referred to as geo-referenced data. By showing a birds-eye view of a given feature, such as a house and its surroundings (i.e. streets, fire hydrants, utilities, and forests), the imagery serves as a powerful tool for analysts to better understand their environment and make more informed decisions.

Aircraft and satellites gather remote sensing imagery. Traditionally, photographs of the Earth were taken from airplanes. An archive of photographs dating to the 1940s is available from the United States Geological Survey (Lillesand and Kiefer, 1994:170). USGS routinely takes new aerial photographs of the entire United States every five to seven years (USGS Products and Publications, 2002). Analysts can detect changes in the landscape by comparing photographs from different dates. Photography is increasingly being replaced by digital (electronic derived) imagery. The term imagery is used generally to include photographs as well as digital images. Satellite imagery of the earth has been collected and archived since the 1970s (Jensen, 2000:184-186). Newer satellites make multiple orbits of the earth, providing the capability to cover any point on Earth every several days. Remote sensing instruments, which measure electromagnetic

radiation reflected by Earth features, are ideal for viewing and monitoring large land areas.

The discussion of remote sensing imagery covers photographic images including black and white panchromatic, black and white infrared, color, and color infrared. The review of digital imagery includes multi-spectral, radar, and Light Detection And Ranging (LiDAR). Each section includes information on characteristics and potential uses of the imagery. Availability, cost, and limitations are covered at the end of the photographic and digital image sections.

2.1 GeoBase Status

The GeoBase Program involves four areas of influence. Each of these has a specific focus depending on the needs for the GeoBase. The categories include Garrison GeoBase, GeoReach, Expeditionary GeoBase, and Strategic GeoBase. Garrison GeoBase covers the Air Force base-level implementation of GeoBase. GeoReach is used in planning for forward operating locations. Expeditionary GeoBase is for deployed locations. Strategic GeoBase provides information to senior command levels such as MAJCOMs and Air Staff (USAF GeoBase, 2002). This research will focus on Garrison GeoBase. For simplicity, Garrison GeoBase will be referred to as GeoBase in this research. Figure 2-1 is an image of a typical base with infrastructure and natural resources that will be included in the GeoBase. The infrastructure includes facilities and utilities such as buildings, roads, waterlines, electric, sewer, and communications lines. Natural resources included in the GeoBase to name a few are trees, water bodies, and endangered species habitats.

Figure 2-1: Garrison GeoBase Resources (GeoBase Overview Materials, 2003)

GeoBase coverage includes 85 main operating bases in the Continental United States (CONUS) and outside the United States (USAF GeoBase, 2002). Because GeoBase will provide a common framework for organizing installation data, the information will be transferable between organizations and higher headquarters.

GeoBase makes data available from various base organizations or units. Data contributed by base units may be in the form of Computer Aided Drawings (CAD), imagery, or supplemental data about facilities on base. Once this data is compiled into a single database, it is available to all base personnel. This single database makes up a Common Installation Picture (CIP). Figure 2-2 shows the structure of a CIP. Base organizations are indicated along the left side of the image. For example, Civil Engineering (CE), Security Forces (SF), Wing Plans (XP), and Transportation (TRANS) are among the units listed. Architecture, tools, and standards are used to provide a

framework for data resources. The CIP is continually revised and updated with current data that is accessible by all base personnel.

Figure 2-2: GeoBase CIP (USAF GeoBase, 2002)

The current GeoBase program imagery guidance specifies "a high quality image as well as key physical and built-up infrastructure information to allow users to quickly orient themselves to the region" (USAF GeoBase, 2002). This research will investigate additional imagery sources that will enhance GeoBase. Figure 2-3 is an example of a Common Installation Picture (CIP). This is a color image collected by aircraft. Additional data on separate layers of the GIS database include facility numbers, facility polygons shown in yellow, utility lines, main road centerlines, and street names.

This research will determine specific types of imagery that can be used in GeoBase to provide improved capabilities for mission accomplishment. The additional imagery will be available as one layer in a geographical information system (GIS).

Figure 2-3: GeoBase CIP (USAF GeoBase, 2002)

Figure 2-4 is an example of a CIP and GIS user-interface. The user-interface gives the user information regarding installation facilities along with associated attributes. The user-interface is divided into three sections called tiles. The top tile has the CIP and a menu indicating the active layers in the CIP display. For instance, air obstruction waivers have a check mark next to TRAIROBS WAIVER. This layer is indicated in solid red. In the CIP, the locations of the waiver are filled in with solid red. To remove the appearance of the waiver from the CIP, the user mouse-clicks the check mark next to TRAIROBS WAIVER to remove it. The data is still available, but it will not be displayed. This categorization of data layers allows the user a more powerful tool to access particular information from the GIS. The bottom left-tiled window indicates additional attribute information. This information is in the form of a spreadsheet. A

particular facility is selected by the user and highlighted in yellow. Facility A-2, an Earth Mound, is identified as having a waiver. A ground-level image of the Earth Mound is shown in the bottom right tile. This data helps the user to determine information from the available data. This GIS capability can be expanded with imagery from aerial or satellite platforms. With imagery an analyst could determine if the earth mound had vegetation coverage without the need of a ground-level image. Near-infrared imagery would provide this capability and is covered in Section 2.3.2, 2.3.4, and 2.4.1.

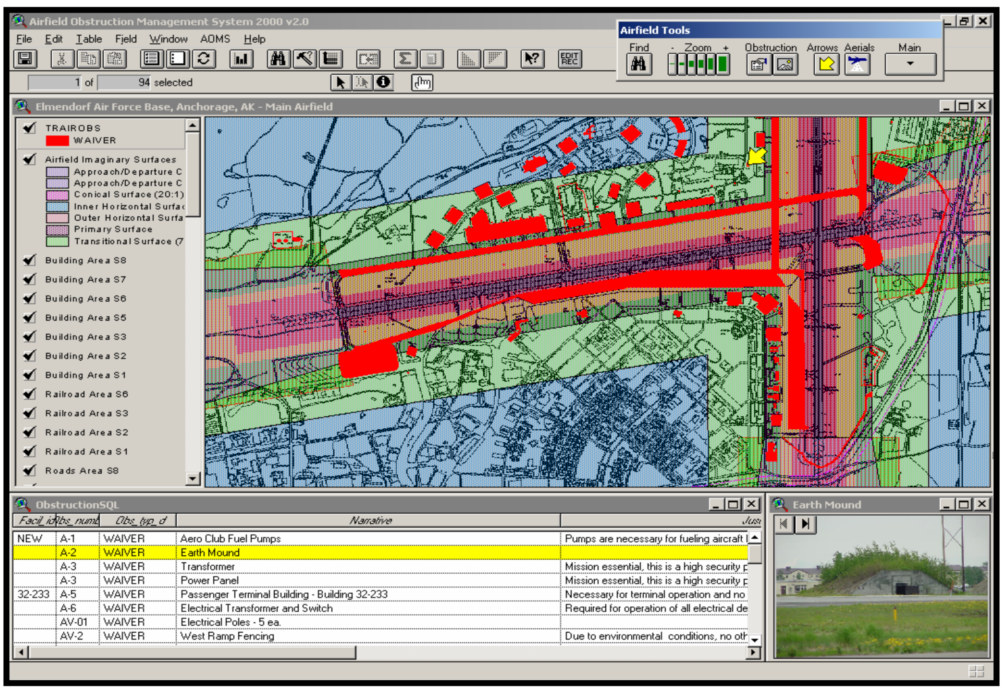


Figure 2-4: GeoBase CIP (USAF GeoBase, 2002)

GeoBase is available on a desktop personal computer and provides geospatial information capability to existing programs such as Automated Civil Engineer System, (ACES) and Theater Battle Management Core System-Unit Level (TBMCS-UL). Personnel at the base level will manage GeoBase with MAJCOM Geo Integration Office

(MAJCOM/GIO) coordination. Each Air Force base has unique requirements that will be fulfilled at the base level. Nationwide, Air Force installations are in the process of implementing GeoBase capabilities. Installations are on their own schedule, and some already have an operational GeoBase (USAF GeoBase, 2002).

2.2 Remote Sensing

Remote sensing is the process of obtaining information about a geographic area from a remote location by means of photographs and electronic sensors. This thesis uses imagery as general terminology to include both photographs and digital images (collected with electronic sensors). Determining the type of imagery to use for a given problem has the potential to create a more powerful GeoBase. Efficiency is gained by demonstrating that many problems can be solved with the same imagery. Remote sensing imagery adds value to GeoBase for current and future needs. By identifying the appropriate use of remote sensing products to solve Air Force problems, users are equipped with a powerful decision-making tool.

Remote sensing can be applied to problems successfully when there is a thorough understanding of the problem as well as the strengths and limitations of the chosen imagery (Lillesand and Kiefer, 1994:35-36). Lillesand and Kiefer note that a favorable outcome of remote sensing application includes many considerations. They offer several recommendations.

> …designs of successful remote sensing efforts involve, at a minimum, (1) clear definition of the problem at hand, (2) evaluation of the potential for addressing the problem with remote sensing techniques, (3) identification of the remote sensing data acquisition procedures appropriate to the task, (4) determination of the data interpretation procedures to be employed and

the reference data needed, and (5) identification of the criteria by which the quality of information collected can be judged (1994:35).

Remote sensing makes use of the electromagnetic spectrum. Figure 2-5 is a diagram of the electromagnetic spectrum. Wavelengths of electromagnetic energy are indicated in meters. Because remote sensing typically uses the ultraviolet, visible, infrared, and microwave sections of the electromagnetic spectrum; micrometers (µm) is often used to discuss wavelengths. Images are made that represent the ultraviolet, visible, infrared, and microwave wavelengths. Each of these will be discussed in detail throughout Chapter 2.

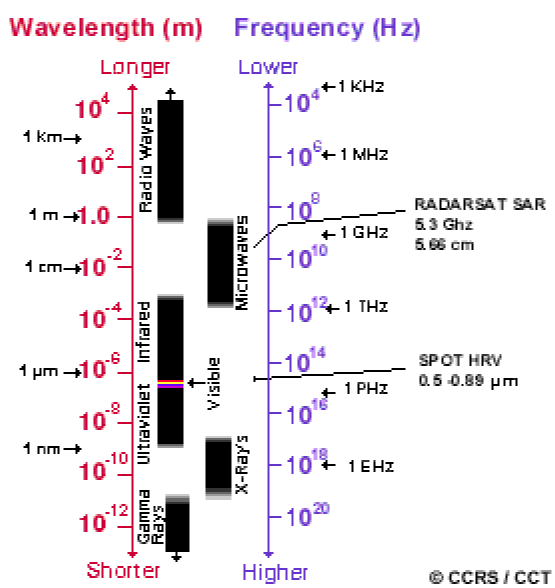


Figure 2-5: Electromagnetic Spectrum (Fundamentals of Remote Sensing, 2002)

2.3 Photographic Images

Photographic systems use light sensitive film to take pictures of a geographic area. Photographs do not involve as much complexity and expense as digital systems.

Photographic images include black and white panchromatic, black and white infrared, color, and color infrared film. A photograph typically has distortions in size and shape of features. Some factors that contribute to distortion include a feature's distance from the center of the photograph and the angle the photograph is taken. A digital orthophoto quadrangle (DOQ) corrects these discrepancies so users can measure true distances directly from the image. Excellent spatial resolution is available with photographs. Spatial resolution is the size of the smallest identifiable feature on the image. It is clearly distinguished and separate from adjacent objects (Lillesand and Kiefer, 1994:23, 33). An image resolution of 1-meter typically allows the analyst to see features as small as one square meter. Features smaller than one square meter will not be recognizable. Resolution is essential to image interpretation in order to distinguish features of interest in an image (Lillesand and Kiefer, 1994:23).

The images in Figure 2-6 and Figure 2-7 demonstrate the concept of spatial resolution. In Figure 2-6, the scale of the photograph is 1:100,000. This imagery is useful for making general observations and decisions regarding a vast geographic area and therefore would not be useful in urban applications.

Most imagery collected currently uses spatial resolution, not scale to determine the amount of detail visible. However, scale is traditionally used when discussing the spatial resolution of photography. Researchers calculated a value to compare photographic scale to spatial resolution. Photograph scale can be compared to spatial resolution with 1:100,000 scale approximately equivalent to 2.5-meter resolution. There is also a "general linear relationship for larger scale aerial photography…"(Jensen and Cowen, 1999:614). With this linear (proportional) relationship, it is easy to calculate that

Figure 2-6: Spatial Resolution Harrisburg Scale = 1:100,000 (Short, 2002)

the 1:4000 scale photograph shown in Figure 2-7 has an approximate spatial resolution of 0.1-meter. This imagery is useful for many urban applications. The analyst can see cars on the highway and a subdivision with individual homes in the image.

Smaller spatial resolution makes it easier for analysts to differentiate ground features in an image. According to Jensen, imagery with 2-meter spatial resolution or higher works well for interpreting urban information. Imagery at 5-meter resolution is poor for interpreting urban information, and 10-meter or lower resolution imagery is practically useless for urban applications (2000:16). Jensen and Cowen give an excellent example of the spatial resolution needed to delineate a feature.

Figure 2-7: Urban Harrisburg 1:4,000 (Short, 2002)

> Another general spatial resolution rule is that there needs to be a minimum of four spatial observations (e.g., pixels) within an urban object to identify it. Stated another way, the sensor spatial resolution should be one-half the diameter of the smallest object-of-interest. For example, to identify mobile homes that are 5 m wide, the minimum spatial resolution of high quality imagery without haze or other problems is ≤ 2.5- by 2.5-m pixels (1999:614).

2.3.1 Black and White Panchromatic Photographs

Black and white photographs are typically produced with panchromatic film. The sensor collects electromagnetic energy in the visible spectrum and produces a gray-scale photograph. Black and white panchromatic film has a spectral sensitivity that records electromagnetic energy from the ultraviolet and visible parts of the spectrum, 0.3μm to

0.7µm (Lillesand and Kiefer, 1994:76-77). Figure 2-8 and Figure 2-9 indicate the location and range of ultraviolet and visible wavelengths on the electromagnetic spectrum.

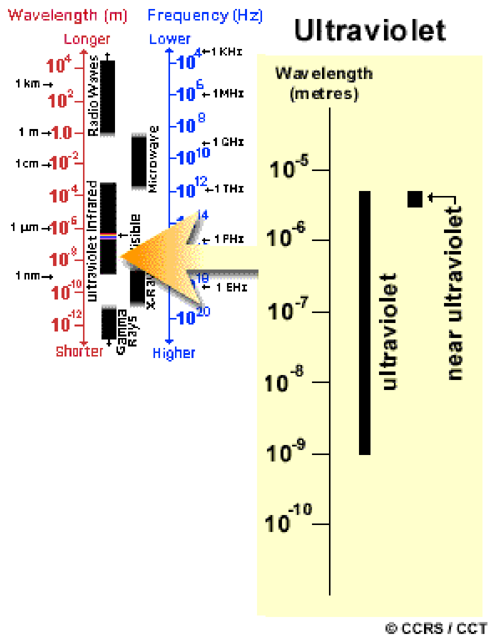


Figure 2-8: Ultraviolet (Fundamentals of Remote Sensing, 2002)

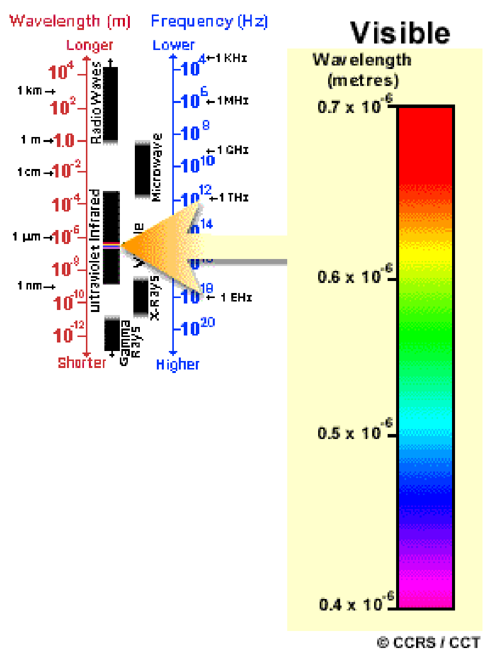


Figure 2-9: Visible (Fundamentals of Remote Sensing, 2002)

2.3.1.1 Characteristics

Photograph scale traditionally ranges from 1:6000 to 1:130,000. A 1:6000-scale, means that 1" measured on the photograph equals 6,000" or 500' in true distance on the ground. Three levels of scale are used to categorize photographs. A small-scale image has a scale of 1:50,000 to 1:130,000. A medium-scale image covers 1:12,000 to 1:50,000. A large-scale image encompasses 1:6000 to 1:12,000 (Lillesand and Kiefer, 1994:154-155). Large-scale images provide more detail than medium or small-scale images.

2.3.1.2 Potential Uses

There are a multitude of uses for black and white panchromatic photography. Urban planners use photography because of the excellent spatial resolution and full coverage of the United States. Since photography of the United States was taken over many years, analysts can retrieve archived photographs and compare these to more recent images, identifying significant changes in the landscape. Panchromatic photographs have been used for planning and urban change analysis since the 1940s (Lillesand and Kiefer, 1994:170).

For help in land-use planning, soil mapping provides information on the types of soils in a geographic location. The United States Department of Agriculture (USDA) uses photo mosaic soil maps with medium-scale black and white panchromatic images as a base. These maps, available since 1957, also come in a digital file format. These maps can be useful for rangeland planning, wildlife habitat assessment, and determining land-use suitability to recreation and development (Lillesand and Kiefer, 1994:181-2).

Aerial photography is used as a tool in managing forests and combating fire. By using imagery, identification of individual tree species is possible through characteristics such as shape, size, pattern, shadow, tone, and texture. Specifically, medium-scale photography has been used for tree species identification. Black and white panchromatic photographs have aided in forest management efforts (Lillesand and Kiefer, 1994:192).

Natural resource and wildlife managers identify animals with white fur by focusing on the ultraviolet portion of the spectrum using black and white panchromatic film. A special filter on the camera that absorbs visible energy wavelength permits the camera to detect only the ultraviolet energy. White-coated seal pups, polar bears, arctic foxes, and hares are easily identified using this technique. Their coats absorb the UV energy and appear black on the photograph (Lillesand and Kiefer, 1994:78-79).

Panchromatic photographs were used in a 1995 study to evaluate land-use changes over time. The analysts used photographs of western Phoenix, Arizona from seven dates covering 32 years. The photography scale ranged from 1:8,000 to 1:21,000. Landfill area decreased from 79 hectares in 1976 to 52 hectares in 1981. By comparing photography from 1985 to photography from earlier dates, researchers determined that many abandoned landfill sites had been converted to urban undeveloped land and public land. The population of western Phoenix was unaware of a possible human health risk from municipal and industrial waste disposal landfill sites. Researchers discovered, with the aid of a Soil Conservation Service map, that soils of these former landfill sites had poor properties for containing waste and pesticides. Several landfill sites were located along the Salt River, which flooded in 1980 and 1993. Seepage and flooding problems may have led to groundwater contamination. The study demonstrated that "Historical

photography is especially useful in the location of inactive or ‘abandoned’ sites or, in many cases, sites that have been buried and subsequently developed”(Mack et al, 1995:1017-1020). Potential human health risks were identified using historical panchromatic photography with additional resources.

2.3.2 Black and White Infrared Photographs

Black and white infrared photography records energy from the ultraviolet (UV), visible and near-infrared parts of the spectrum from 0.3μm to 0.9μm. This film has a wider spectral sensitivity than black and white panchromatic film and can detect the near-infrared spectral band that humans are incapable of seeing. The imagery product is a more complex snapshot from which analysts are able to separate features based on near-infrared reflectance.

2.3.2.1 Characteristics

A camera filter is used to collect only the near-infrared electromagnetic energy wavelengths from 0.7μm to 0.9μm. The filter allows only near infrared to pass through and create a photograph. Figure 2-10 shows the infrared section of the electromagnetic spectrum. The near infrared is used for photography. Mid-infrared and thermal-infrared are discussed later in the multi-spectral digital imagery section. Frequency, in hertz (Hz), is another measure of the wavelengths in the electromagnetic spectrum. Black and white infrared photography has an upper limit to sensing the electromagnetic spectrum because of the “photochemical instability of emulsion materials.” The lower limit of spectral sensitivity is due to the atmosphere and glass camera lens absorbing electromagnetic energy as well as the effects of atmospheric scattering (Lillesand and Kiefer, 1994:77).

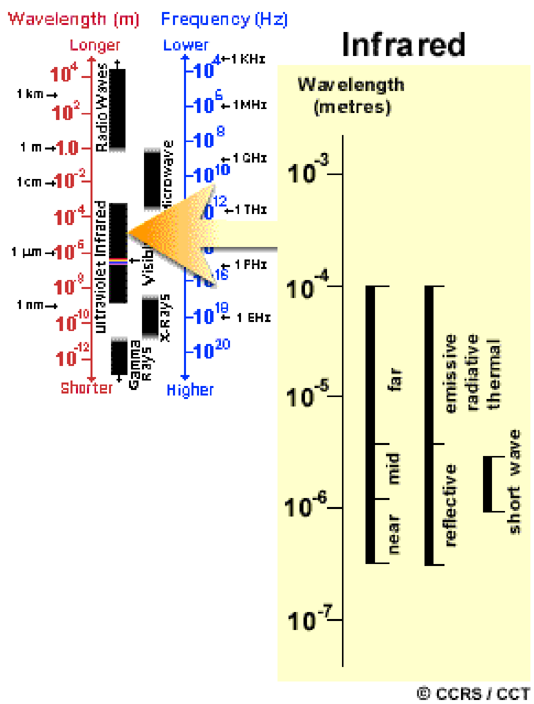


Figure 2-10: Infrared (Fundamentals of Remote Sensing, 2002)

2.3.2.2 Potential Uses

Black and white infrared photography is appropriate for a wide range of environmental applications. Some of these include forest, agricultural, rangeland, wetland, and urban vegetation management. The management of habitats for endangered species is possible by determining the amount and type of vegetation in a geographic area. The spectral reflectance of the near-infrared wavelength can distinguish deciduous trees from coniferous trees. Electromagnetic energy is reflected in varying amounts depending on the type of tree (Jensen, 2000:126). A sensor records the reflected infrared energy, and an image is formed. According to Lillesand and Kiefer, “On black and white infrared photographs, deciduous trees (having higher infrared reflectance than conifers) generally appear much lighter in tone than do conifers” (1994:15). This ability to

distinguish deciduous from coniferous trees makes it easier to identify the amount of land covered by each type of tree. With this information, the habitat of animals that depend on a certain type of tree in the region can be studied. This is a significant advantage of black and white infrared photography over black and white photography. Analysts cannot distinguish between deciduous and conifer trees using black and white photography.

Figure 2-11 details the capability of infrared imagery to distinguish between healthy vegetation and stressed vegetation. The spectral reflectance of healthy and stressed vegetation is similar in the visible portion (0.4-0.7μm) of the electromagnetic spectrum. Imagery using the infrared portion of the electromagnetic spectrum allows analysts to discern between healthy and stressed vegetation. Healthy vegetation has a high near-infrared (0.7-1.1μm) reflectance of electromagnetic energy, while stressed vegetation has a low reflectance in the near-infrared region. In a near-infrared image the healthy vegetation will have a brighter shade of gray for black and white infrared imagery, or typically a brighter red color for multi-spectral imagery.

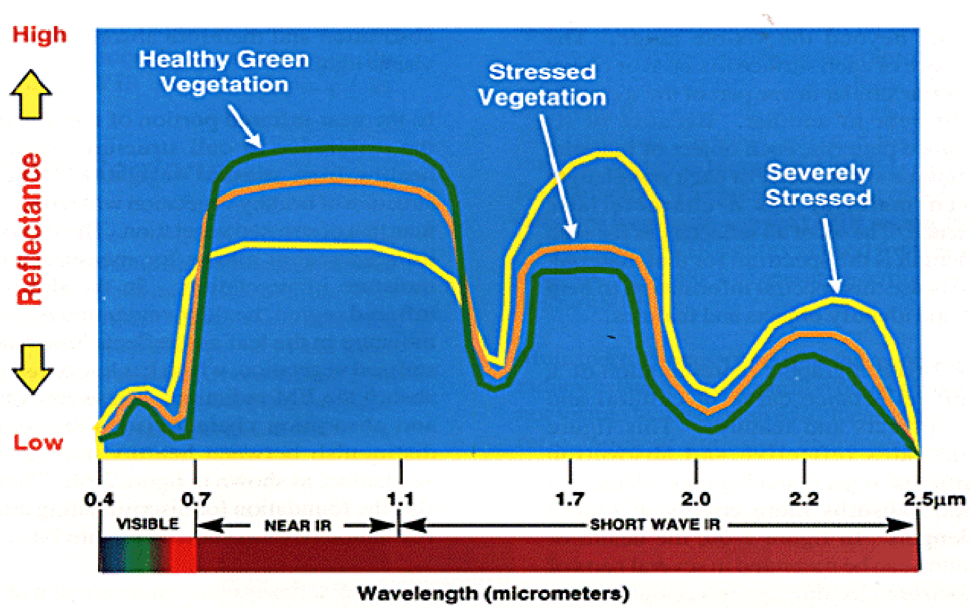


Figure 2-11: Spectral Reflectance of Vegetation (Remote Sensing: The Logistics, 2003)

2.3.3 Color Photographs

Color film is used to record electromagnetic energy in blue, green, and red light wavelengths. These visible light wavelengths range from 0.40 μm to 0.70 μm. Color photographs allow for more distinction than black and white photographs because it is easier for people to discern millions of color variations than just 32 tones of gray (Lillesand and Kiefer, 1994:79, 81).

2.3.3.1 Characteristics

Color photographs are recorded using three layers of information. A yellow dye records the blue light wavelength; magenta dye records the green light wavelength; cyan dye records the red light wavelength (Lillesand and Kiefer, 1994:81). Figure 2-12 shows a side-by-side comparison of a color photograph (on the left) and a color-infrared photograph (on the right). The color photograph allows the analyst to view features in natural colors. The color-infrared photograph will be discussed further in the next section.

Figure 2-12: Color and Color-Infrared (Remote Sensing of Vegetation, 2002)

2.3.3.2 Potential Uses

Color photographs are useful for land and urban management. Applications range from traffic studies to disaster response. If color photography is available and preferred over black and white photography, it may be used in applications where black and white photography is used. Color photography is easier to understand because people are used to seeing everything in color. People without training in the use of black and white photography or infrared photography will find it easier to use color photography. The Air Force also places a high priority on community planning, and color photography will make compliance with architectural standards, including color and style of buildings, easier. Prices for photography are discussed in Section 2.3.6.

Planners who are inexperienced at interpreting black and white photography may find color photography easier to interpret. In their analysis of Phoenix, Arizona environmental hazards, Mack et al. used available color and color-infrared photography to supplement black and white panchromatic. The authors noted that the color photography and additional analysis information "was a useful reference for the recognition and interpretation of solid and liquid waste disposal sites" (Mack et al., 1995:1017).

2.3.4 Color Infrared Photographs

Color infrared photographs provide several advantages over black and white, black and white infrared, and color photographs. Analysts use color-infrared photographs to identify health and abundance of vegetation, land-water boundaries, suspended sediment and organic matter in waterways, and camouflaged resources.

2.3.4.1 Characteristics

Color-infrared film records electromagnetic energy in the ultraviolet, blue, green, red, and near-infrared light wavelengths from 0.3μm to 0.9μm. The infrared wavelength from 0.7 μm to 0.9 μm provides additional capabilities over color film.

A camera filter is used to prevent ultraviolet (UV) and blue light from exposing the film. The UV and blue light wavelengths naturally scatter in the atmosphere. Filtering these wavelengths makes a clearer photograph. The green, red, and near-infrared wavelengths expose the film. The electromagnetic energy is collected and portrayed on the film in false colors to incorporate the infrared wavelengths, because infrared is colorless. The near-infrared wavelength gives imagery analysts the ability to separate features with varying amounts of near-infrared reflectance (Jensen, 2000:116).

2.3.4.2 Potential Uses

Figure 2-12 shows a comparison of urban color and color-infrared photographs. With the color-infrared photograph on the right, it is easier for an analyst to identify the health of vegetation. The healthier vegetation is bright red. Figure 2-13 shows a color photograph on the left compared to a color-infrared photograph on the right. In the color-infrared photograph, the area of water is black because it is devoid of suspended sediment or organic matter. With color-infrared photography, the sensor records infrared energy reflected off of vegetation, which appears red by convention. As shown in Figure 2-13, it is much easier to see the boundary between water and land in the color-infrared photograph than in the color photograph.

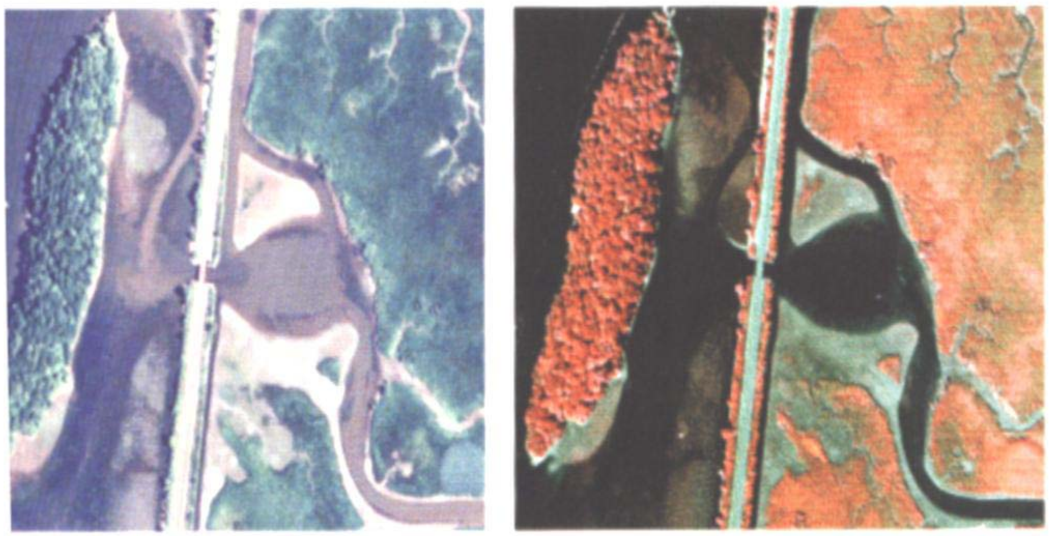


Figure 2-13: Color vs. Color-Infrared Photograph (Jensen, 2000:Plate 4-3)

Waterways that have sediment or organic matter will reflect infrared energy, making the water appear lighter in the image. By comparing color and color-infrared photographs, an analyst can determine portions of a waterway with high amounts of polluting sediment or organic matter. Unlike color photography, color-infrared photography is suitable for detecting sediment and organic matter that degrades water quality. This data can be used to perform water quality monitoring. During this process, color-infrared photography is combined with additional geo-spatial information including hydrology, topography, and soil data in a GIS database. The geo-spatial information allows researchers to determine peak flow of water and soil erosion caused by storms. This analysis may also be used by the military in formulating similar soil erosion models. Some researchers have used 1:10,000-scale color-infrared photography and 3-meter multi-spectral data to determine the land-cover information for a geographic area. Multi-spectral images will be covered in a later section. With this information, researchers

identify potential problem areas that require “vegetated buffer strips and other best management practices” (Jensen, 2000:403-404).

During WWII, the U.S. military required a technology to detect camouflaged targets. Researchers determined that chlorophyll in vegetation reflects infrared energy. This phenomenon does not occur with camouflage or any other non-vegetation. The color-infrared photograph was successfully used by the military in WWII to locate targets covered with camouflage (Jensen, 2000:114-115).

2.3.5 Photography Availability

One of the most extensive inventories of imagery products is maintained by the United States Geological Survey (USGS). USGS has an archive of more than eight million aerial photographs. Black and white panchromatic, black and white infrared, color, and color-infrared photographs are offered by the USGS. Most of these photographs have a scale of 1:40:000. Photographs with a scale of 1:24,000 are also available. Digital images of the photographs called digital orthophoto quadrangles (DOQ) are also available from USGS. The distance of ground features may be measured directly from DOQ files, because the photo is geometrically corrected to reflect true distances. Digital orthophoto quadrangles are available in either black and white, color, or color-infrared in a variety of formats including CD-ROMs, 8 mm tape, electronically through file transfer protocol (FTP), and digital versatile disc-recordable (DVD-R) (USGS Products and Publications, 2002).

USGS and other national agencies have been taking aerial photographs on a regular basis since the 1940s, and these are available for a nominal fee. Photographs can be ordered through the USGS website at www.usgs.gov or by calling

1-800-ASK-USGS (257-8747).

Panoramic photography is available from the U.S. Forest Service (USFS) and the U.S. Environmental Protection Agency (EPA). Panoramic photography provides a series of images for an area of interest. The USFS has 1:15,840-scale photography, while typical EPA photography is 1:6000-scale (Lillesand and Kiefer, 2000:197-199).

The National Imagery and Mapping Agency (NIMA) is a major source of aerial photography (Commercial Imagery Copyright & License Interim Guidance, 2002). SPIN-2 aerial photography at 1:10,000 and 1:50,000 scale, has been collected since 1981 by the Russian Space Agency (Jensen, 2000:235-238).

The U.S. Department of Agriculture Agricultural Stabilization and Conservation Service (USDA-ASCS) have been taking aerial photographs regularly since 1937. The scale of the photography at USDA and archived USGS photography generally is 1:20,000 (Lillesand and Kiefer, 2000:197-199).

The National Aeronautics and Space Administration (NASA) has collected photographs at scales of 1:60000, 1:65,000, 1:120,000 and 1:130,000. (Lillesand and Kiefer, 2000:197-199).

Private companies also provide photographs and DOQ's as well as additional products. Photography is available from an archive or on demand by hiring a company to take photography. Archived photography is significantly less expensive, provides a wealth of data about a geographic area, and covers many dates. On-demand photography is available through many companies and can provide updated data each day for dynamic situations such as disaster response. Some examples of private companies that

provide on-demand aerial imagery and GIS value-added products are Leica Geosystems and Surdex Corporation (Hoffmann, 2002).

2.3.6 Photography Cost

The cost of archived USGS aerial photograph products ranges from $10.00 for a 9" square black and white panchromatic photo to $75.00 for a 36" square color or color infrared photograph. The 9" photograph covers approximately five square miles. Geometrically corrected data such as the digital orthophoto quadrangle costs $37.50 to download a copy from USGS to your computer. A digital versatile disc-recordable (DVD-R) costs $67.50 per copy. A handling fee of $5.00 is charged for each product. Private companies also provide special order products with prices dependent on the data and format requested (USGS Products and Publications, 2002).

The cost of on-demand aerial imagery depends on the requirement of the user. Planners in Martin County, Florida, estimated that to collect geo-referenced aerial photography for a countywide GIS would cost $125,000. Planners were able to use SPOT satellite imagery instead, at a cost of approximately $5,000. Martin county also has the flexibility to make annual updates to the GIS, monitoring growth and land-use changes (Florida's Martin County develops a GIS to manage future growth, 2002).

2.3.7 Photography Limitations

A limitation of photography is that an analyst requires sufficient training to understand and interpret images that use different parts of the electromagnetic spectrum. Most people do not easily interpret black and white panchromatic photography. Because we see in color, specialized training is required to understand and interpret black and

white photography. Infrared photography is even more complex, but provides more capabilities to the skilled analyst.

Remote sensing does not provide all the information needed to solve problems. Supporting information such as ground sampling must be used with remote sensing photography. Human beings must choose the correct type of photography or image to conduct analysis. Choosing the wrong remote sensing image to solve problems or interpreting the data incorrectly will invariably lead to errors (Jensen, 2000:7).

2.4 Digital Images

Digital images are created when electronic sensors collect data from a geographic area and a computer generates a picture. Multi-spectral, radar, and Light Detection And Ranging (LiDAR) are examples of electronic sensors. While multi-spectral and radar produce two-dimensional images, LiDAR generates three-dimensional images (Lillesand and Kiefer, 1994:23).

2.4.1 Multi-spectral Digital Image

Multiple sections of the electromagnetic spectrum are used to create a multi-spectral image. These sections are called spectral bands. Each spectral band accounts for either a visible, infrared, or thermal section of the electromagnetic spectrum.

Over the past 30 years there has been much advancement in imagery resolution and the number of satellites collecting imagery. Imagery is available from many satellite programs including Landsat, Quickbird, IKONOS, OrbView, *Systeme Probatoire d'Observation de la Terre* (SPOT), Indian Remote Sensing (IRS), National Aeronautics and Space Administration (NASA) Terra, and Russian SPIN-2. Landsat imagery has

been collected continuously since 1972 providing an archived database. SPOT, a French satellite program, has provided imagery since 1986. In terms of imagery spatial resolution, SPOT has stayed one step ahead of Landsat; however, Landsat has thermal imagery capability. The IRS satellite program has collected imagery since 1988 with later-generation satellites providing improvements in resolution. SPIN-2 is Russian satellite imagery that collects digital panchromatic imagery that has similar capability to the later generation SPOT-5 panchromatic imagery. SPOT, Landsat, and IRS imagery does not provide as high a spatial resolution as the newer imagery systems, IKONOS, Quickbird, and OrbView. IKONOS imagery is available from 1999 to present, and Quickbird imagery is available from 2001 to present providing some of the highest resolution capability. OrbView later-generation satellites provide high-resolution imagery starting in 2002 that is comparable in resolution to IKONOS and Quickbird. NASA's Terra satellite has captured imagery with a sensor called Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) since 1999. ASTER focuses on collecting data in many infrared bands including thermal infrared at a lower spatial resolution than IKONOS, Quickbird, and OrbView. With the exception of Quickbird and IKONOS, each of these satellite programs is represented by several generations of satellites as technology has improved collecting capability. Quickbird, IKONOS, SPOT, and IRS have plans to launch improved satellites within the next three years (Status of Selected Current & Future Commercial Remote Sensing Satellites, 2002).

Aerial platforms are used to collect multi-spectral imagery with the Daedalus and Advanced Thermal and Land Applications Sensor (ATLAS) multi-spectral scanners. Daedalus has been used in 25 countries over the past 30 years (Jensen, 2000:209).

NASA's ATLAS is a more recent multi-spectral scanner, used in several applications in the late 1990s (Jensen, 2000:212; Description of the ATLAS Remote Sensing System, 2002).

2.4.1.1 Characteristics

Multi-spectral digital images collect data from the ultraviolet, visible, near infrared, and often mid-infrared and thermal-infrared wavelengths; and imagery is available in a range of spatial and temporal resolutions. Each satellite remote sensor has unique spectral bands that collect this data on the various wavelengths. The spatial and temporal resolution capabilities of satellite and aerial platforms vary with newer satellite platforms approaching the spatial and temporal resolution capability of aerial platforms while covering a larger geographic area on a frequent basis.

The Landsat satellite platform has multiple satellites providing multi-spectral imagery. The generations of Landsat satellites follow the numbering convention of Landsat-1, Landsat-2, and so forth up to Landsat-7. Landsat-1, 2, and 3 have a Multi-Spectral Scanner (MSS) that collects electromagnetic energy in the visible and near-infrared wavelengths. The spatial resolution is 56 x 79 meters for each image. Temporal resolution, or the time it takes for the Earth-orbiting satellite to return to the same geographic area, is 18 days (Jensen, 2000:184-197).

Landsat-4 and Landsat-5 have both a Thematic Mapper (TM) sensor and the Multi-spectral Scanner (MSS) (Jensen, 2000:192-197). Often the terminology of Landsat-4, Landsat-5 and Landsat TM is used interchangeably because these later generation satellites added the Thematic Mapper capability. The Landsat TM operates using seven spectral bands that collect data at specific electromagnetic wavelengths.

Visible blue, green, and red light bands are utilized, as well as the near infrared, mid-infrared (2 spectral bands), and thermal infrared band. Landsat TM produces digital images of the earth with a 30 x 30 meter spatial resolution. The thermal infrared band has a spatial resolution of 120 x 120 meters. Landsat TM collects imagery of the same geographic area every 16 days (Jensen, 2000:192-197; Lillesand and Kiefer, 1994:467-471).

Landsat-7 Enhanced Thematic Mapper Plus (ETM+) is the latest generation Landsat satellite. The Landsat ETM+ has a panchromatic band, multi-spectral capability similar to Landsat-TM and an improved thermal infrared band. The spatial resolution of each of these is 15 x 15 meter, 30 x 30 meter and 60 x 60 meter respectively. The temporal resolution is the same as Landsat-TM, with 16 days between revisits over the same geographic area (Jensen, 2000:197-201). Figure 2-14 is an image from Landsat-7 ETM+. Forest fires burning in South Dakota were captured the morning of July 1, 2002. The multi-spectral image indicates fire in red and orange, burn scars in dark red, and forest in dark green. The entire area exposed to fire is outlined in yellow (Fires in Wyoming and South Dakota, 2002). Managers use this information to make informed decisions concerning how to fight the forest fires and evacuate people in the area affected by the fire and smoke.

Quickbird spatial resolution is 0.61 x 0.61 meter black and white panchromatic and 2.5 x 2.5 meter multi-spectral (Quickbird, 2002). Quickbird has stereoscopic capability as well. The imagery, collected in side-by-side pairs, is referred to as a stereoscopic image. An analyst can see three-dimensional data by using stereoscopic images. Quickbird may collect imagery of the same geographic area every one to five

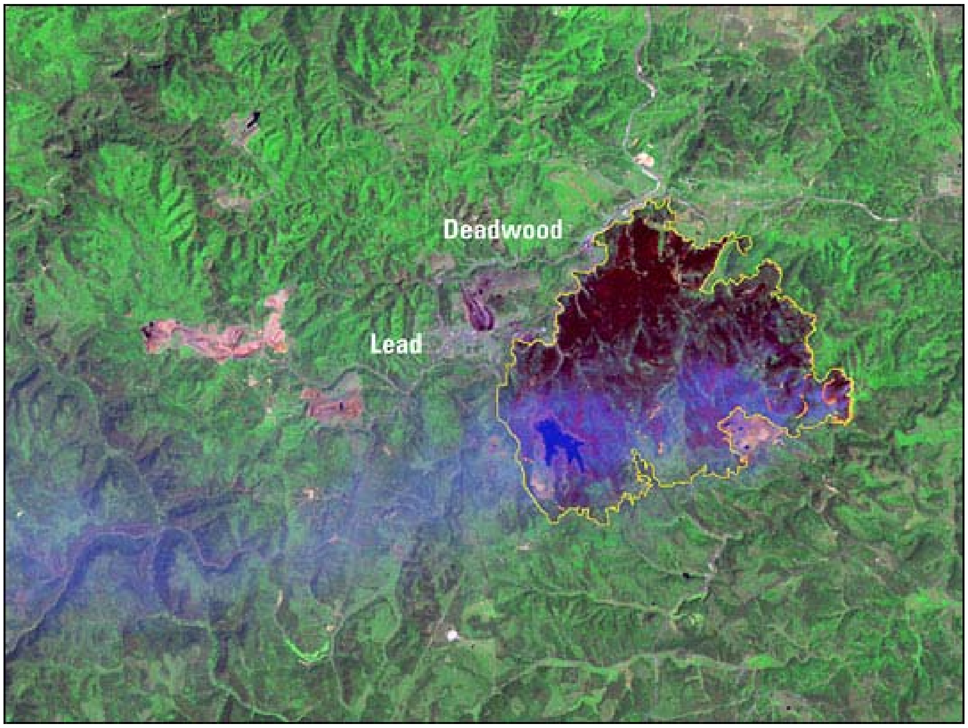


Figure 2-14: Landsat-7 ETM+ (Fires in Wyoming and South Dakota, 2002)

days dependent on latitude (Jensen, 2000:224). The Quickbird image in Figure 2-15 is a natural-color image of the Boneyard at Davis-Monthan AFB. A panchromatic 0.61-meter spatial resolution image was collected by satellite on August 11, 2002. Out-of-service aircraft are shown with surrounding hard desert soil (The Boneyard, Davis-Monthan AFB, Tucson, AZ, 2002). The natural-color image is produced by assigning colors to the gray-scale panchromatic image with a GIS software package.

IKONOS has 1 x 1 meter panchromatic and 4 x 4 meter multi-spectral spatial resolution. The multi-spectral bands collect data in the visible and near-infrared wavelengths. The temporal resolution, frequency of collection over the same geographic area, is 2.9 days at 1-meter resolution and 1.5 days at 1.5-meter resolution (IKONOS, 2002).

Figure 2-15: Quickbird Multi-Spectral Image (The Boneyard, Davis-Monthan AFB, Tucson, AZ, 2002)

Figure 2-16 is an IKONOS panchromatic image of Green Island, Kuwait. The artificial island covers 785,000 square meters and is connected to the mainland by a 134-meter roadway. Also, easily seen in the 1-meter image are roadways and buildings (IKONOS 1-meter Pan-Sharpened Image of Kuwait, 2003).

OrbView has 1 x 1 meter panchromatic and 4 x 4 meter multi-spectral spatial resolution. Satellites OrbView-3 and OrbView-4 collect imagery with a temporal resolution of less than three days. OrbView does not have thermal infrared capability (Jensen, 2000: 226). Figure 2-17 is a 1-meter OrbView-3 panchromatic of Las Vegas, Nevada. This imagery when applied to urban applications makes large structures easily distinguished. Cars are also visible in the image.

OrbView also has a 4-meter multi-spectral capability. Figure 2-18 shows crops in California (Image Gallery-Simulated OrbView-3 four meter multi-spectral image of

Figure 2-16: Green Island, Kuwait (IKONOS 1-meter Pan-Sharpened Image of Kuwait, 2003)

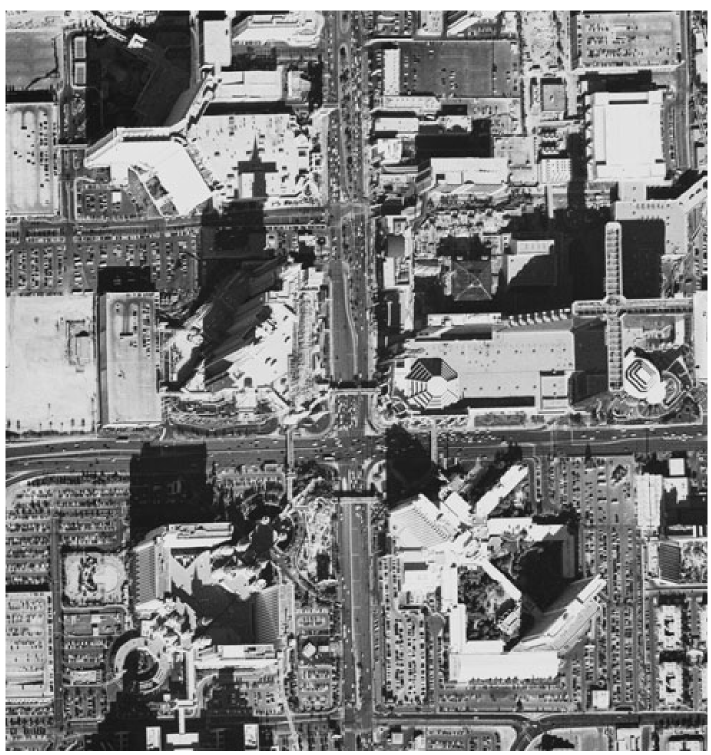


Figure 2-17: 1-Meter Panchromatic (Image Gallery-OrbView Cities one-meter image of Las Vegas, Nevada, 2003)

Castroville, California, 2003). Managers could use multi-spectral images such as this to determine the health of vegetation and the amount of water used for irrigation. With this multi-spectral imagery the healthy vegetation reflects a higher amount of infrared energy than surrounding fields. When the imagery is processed, the infrared energy recorded is assigned the color red, by convention. With more information about the types of crops planted, natural resource managers can determine the amount of acreage planted. With additional information about the amount of water needed per crop acre, a water resources manger can determine the affect on local aquifers. This is important because often cities use the same aquifer to provide drinking water to inhabitants.

Figure 2-18: 4-Meter Multi-Spectral (Image Gallery-Simulated OrbView-3 four meter multi-spectral image of Castroville, California, 2003)

SPOT satellites 1, 2, 3, and 4 have a spatial resolution of 10 x10 panchromatic and 20 x 20 multi-spectral (Status of Selected Current & Future Commercial Remote Sensing Satellites, 2002). The temporal resolution is every 26 days. SPOT-3 imagery is not available after 1996, having been taken out of service (Jensen, 2000: 212). Archived imagery is available up to 1996 from SPOT-3. When SPOT-1, 2, and 4 satellites are used at the same time, temporal resolution of one day is possible for any geographic area on the Earth (Jensen, 2000:220). SPOT does not have thermal infrared capability (Jensen, 2000:217). SPOT-5 imagery became available in 2002, providing 2.5 x 2.5 meter panchromatic and 10 x 10 meter multi-spectral resolution Status of Selected Current & Future Commercial Remote Sensing Satellites, 2002). The temporal resolution is less than three days depending on latitude. When several SPOT satellites are used together, temporal resolution improves to one day (SPOT satellite programming: a customized service…, 2002). Thermal infrared is not available with SPOT (Jensen, 2000:220).

IRS-1A, 1B provide multi-spectral imagery spatial resolution of 36.25 x 36.25 meter and 72.5 x 72.5 meter. The temporal resolution time is 22 days, or 11 days with both satellites. IRS-1C, 1D provide spatial resolution of 5.8 x 5.8 meter panchromatic, 23.5 x 23.5 meter multi-spectral, and 70 x 70 meter mid-infrared. The temporal resolution is 24 days. IRS does not have thermal infrared capability (Jensen, 2000:220-221).

The Terra satellite, a joint cooperation between NASA and Japan's Ministry of International Trade and Industry, has the ASTER multi-spectral sensor. ASTER collects multi-spectral data on the visible through thermal infrared wavelengths of the electromagnetic spectrum. ASTER has three separate instruments that collect various

portions of the spectrum. The imagery spatial and spectral resolution is 15 x 15 meter visible and near infrared (in stereoscopic coverage for obtaining elevations), 30 x 30 meter near and mid-infrared, and 90 x 90 meter thermal infrared (Jensen, 2000:221-222). The temporal resolution for ASTER is 4 to 16 days (ASTER: Suez Canal, 2002).

SPIN-2 Russian satellite imagery provides panchromatic spectral resolution in both 2-meter and 10-meter spatial resolutions. The 2-meter is available in panoramic view. The temporal resolution is 45 days (Jensen, 2000:235-238).

Aerial multi-spectral sensors provide the high spatial resolution and imagery on demand capability when weather is good such that clouds and precipitation do not interfere with collection. The gap between satellite and aerial capability is quickly closing as the newer satellites obtain spatial and temporal resolutions that are nearly as good as aerial collection. Two aerial multi-spectral sensors are discussed in greater detail.

The Daedalus multi-spectral scanner is available in three generations having been used for the past 30 years. All three provide imagery capability covering the ultraviolet to thermal-infrared wavelengths. Spatial resolution depends on the altitude of the aircraft during imagery collection. The altitude is determined based on the spatial resolution needs of the user and the size of the geographic area to be imaged. There is a trade-off between the spatial resolution and the amount of time needed to collect the imagery. The higher spatial resolution required leads to lower flight altitude above ground level (AGL) and more passes over a geographic area to obtain the imagery. Table 2-1 shows examples of spatial resolution possible at varying AGL. Note that the AGL is given in meters (Jensen, 2000:209-212).

Table 2-1: Spatial Resolution of Aircraft Multi-Spectral Imagery (Jensen, 212)

Flight Altitude AGL (m)	Pixel Size (m)
1000	2.5
2000	5
4000	10
16000	40
50000	125

NASA's Advanced Thermal and Land Applications Sensor (ATLAS) is a multi-spectral sensor mounted on an aerial platform. The ATLAS collects electromagnetic energy from the visible, near-infrared, mid-infrared, and thermal-infrared wavelengths. The spatial resolution capability is nearly twice as high as Daedalus. For example, ATLAS provides multi-spectral imagery with 2.5 x 2.5 m spatial resolution at 6000 ft AGL and 25 x 25 m at 41000 ft AGL. As with Daedalus, ATLAS gives the user on-demand capability for imagery, weather permitting with a Learjet 23 aircraft (Jensen, 2000:212). Figure 2-19 is an image of the Learjet 23 used by NASA to collect imagery with the ATLAS imagery system.

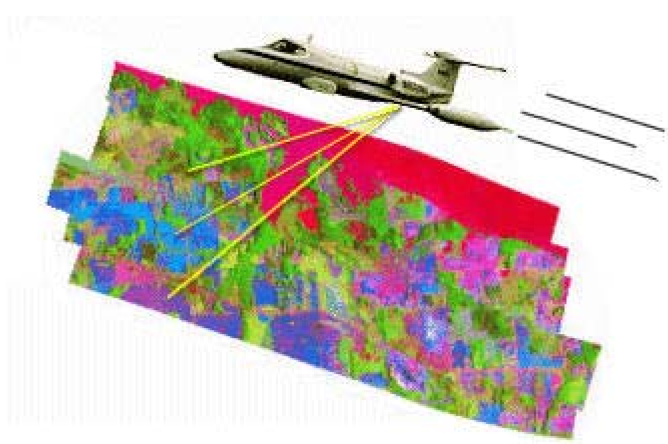
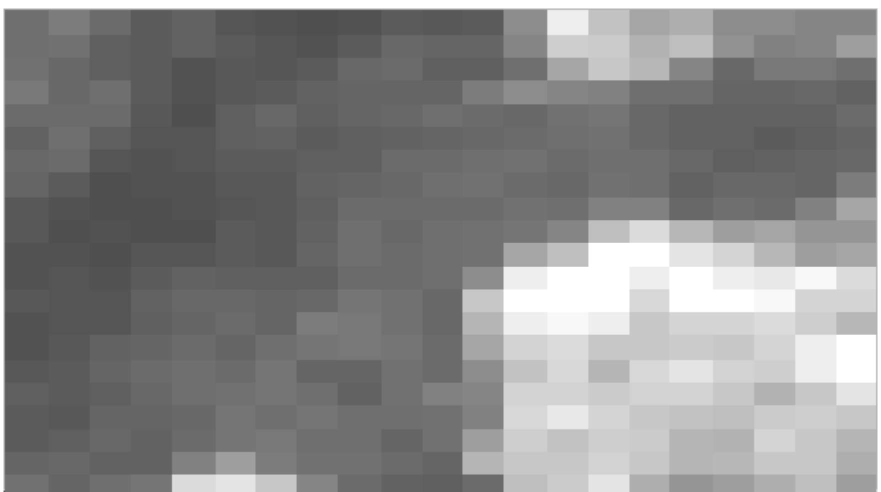


Figure 2-19: NASA ATLAS On-Demand Aerial Imagery Platform (Description of the ATLAS Remote Sensing System, 2002)

The importance of high spatial resolution can be demonstrated by comparing IKONOS to Landsat. An image with a higher resolution such as 1 x 1 meter (IKONOS) has more pixels of the same geographic area covered by only one Landsat pixel. The same 30 x 30 single Landsat pixel would be represented by 900 (30 x 30=900) IKONOS pixels. This provides more spatial resolution detail to the analyst. Figure 2-20 is part of a black and white digital image. The image has been magnified to show the pixels that comprise the image. This unusually high magnification demonstrates the makeup of a digital image.



111	124	107	91	98	85	82	79	82	91	88	91	142	238	194	168	171	142	142	136	136
111	113	95	91	98	91	85	82	91	104	101	101	136	206	203	178	187	145	127	136	161
113	104	95	91	82	88	85	91	104	107	95	95	111	165	199	183	133	104	120	120	111
120	104	111	91	82	88	91	98	101	101	101	124	140	136	129	111	111	101	101	104	98
107	107	107	88	79	95	104	95	101	104	111	107	104	113	117	104	98	98	98	98	107
98	111	95	85	85	95	98	91	95	98	101	104	107	111	113	104	98	98	91	95	101
104	107	85	82	85	91	91	95	95	107	107	111	113	107	111	111	104	95	98	101	104
101	91	79	82	82	88	88	98	101	104	111	113	107	104	113	111	98	104	104	101	124
88	82	79	79	82	85	88	95	107	107	107	107	113	111	127	127	104	111	107	129	165
88	79	82	79	79	91	88	98	111	104	111	113	117	133	187	219	183	161	165	152	149
82	82	79	85	85	91	88	101	111	107	111	113	168	190	255	255	228	212	183	161	168
82	85	82	91	98	95	95	95	107	107	111	142	241	255	255	235	255	238	232	248	219
88	85	85	98	104	104	101	104	117	113	104	197	255	255	255	215	255	255	251	212	212
82	85	85	95	101	107	101	124	120	113	104	181	241	251	235	199	212	212	219	206	183
82	88	98	101	107	101	111	117	120	117	107	165	210	219	199	199	203	199	212	241	255
88	91	101	107	111	107	117	101	101	113	107	140	194	215	181	215	226	210	206	241	255

Figure 2-20: Pixels (Digital Image Processing, 2002)

Each pixel has a gray tone value from 0 to 255 based on the reflectance of electromagnetic energy from earth features. In this image, the white areas correspond to a gravel pit that has high reflectance of electromagnetic energy. The dark pixels correspond to a stream valley that has low energy reflectance (Digital Image Processing, 2002). The pixels that comprise the image in Figure 2-20 have corresponding gray tone values. For instance, in the upper right corner, there is a gray tone value of 136, roughly half way between 0 and 255. The pixel is medium-gray. Three rows down from 136 is value 98. The corresponding pixel in the image is much darker gray. About two-thirds down the same column is value 255. This corresponds to a white pixel in the image. The reflectance recorded in each pixel value makes a composite image of a feature. Features are distinguished based on their values (shades of gray). Multi-spectral images are created similarly, but the reflectance values can be recorded in variations of one of three colors: blue, green and red.

2.4.1.2 Potential Uses

The application capability of multi-spectral digital imagery is the broadest of any of the imagery techniques. With a wide range of the electromagnetic spectrum collected, more applications are possible with multi-spectral imagery. Multi-spectral imagery can be used for any of the requirements of panchromatic, visible, or infrared imagery when the appropriate spatial and temporal resolution is met by the remote sensing platform.

Most of the research to date has used earlier generation Landsat TM imagery. As later generation, more capable satellite imagery becomes available such as IKONOS, Quickbird, and OrbView; researchers will use these to obtain more precise information. The possibilities for determining new information are greater because the newer imagery

has greater resolution capability. The examples provided later in this section may be accomplished with higher resolution imagery available from newer satellites and aerial sensors where the spectral and temporal resolution is improved.

Landsat TM data (30-meter spatial resolution) is used to determine land-cover classification of urban areas. However, spatial resolution is often a problem, prohibiting the visibility of some features. Thirty-meter resolution alone is not adequate for urban analysis. The low pixel resolution creates sub-pixel mixing due to the small spatial size of surface objects. Sub-pixel mixing leads to a pixel color value that is a mixture of the various objects in the 30 x 30 meter area. Objects with the highest spectral reflectance will dominate the 30 x 30 meter area, defining the pixel value. Objects can be misclassified due to their spectral reflectance characteristics (Stefanov et al, 2001:174). Figure 2-21 demonstrates what happens when the spatial resolution is inadequate for the features of interest. The image on the left is the color-infrared aerial photography with 0.5-meter spatial resolution. Using a 30-meter spatial resolution sensor, such as Landsat TM, the image on the right would be produced. The image on the right is a composite of all the features with one pixel color, or sub-pixel mixing. This demonstrates the need for appropriate spatial resolution for the features of interest.

When imagery has spatial resolution that is insufficient for a particular use, surveys (supplemental field research) can improve accuracy of the pixel classification. One additional source of data is referred to as land-use. This type of research is readily obtained from government agencies. Land-use may be classified as agricultural, urban, commercial, rangeland, wetland, tundra, as well as other designations. Since Landsat has amassed a large database of imagery since 1972, various methods for using the imagery

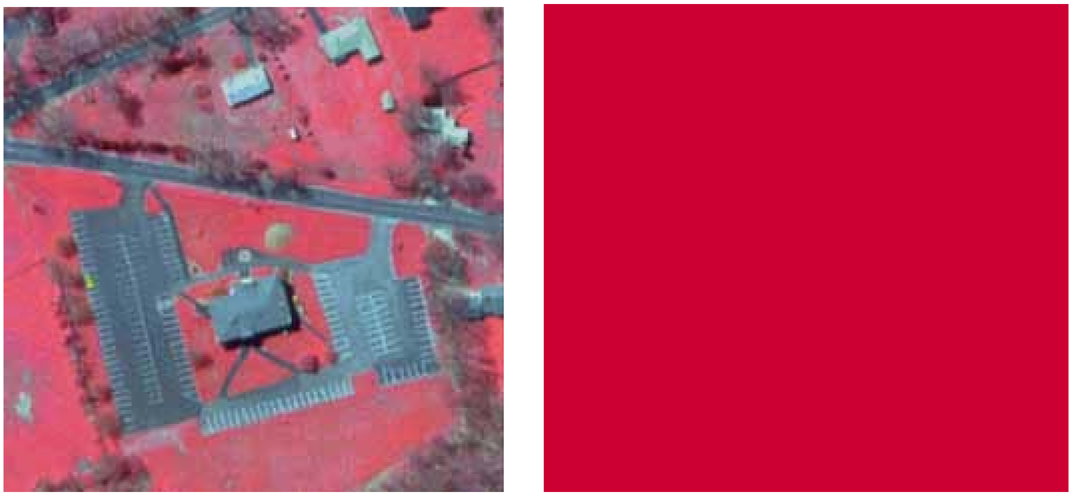


Figure 2-21: Spatial Resolution Comparison (Remote Sensing of Vegetation, 2002)

in urban planning and monitoring have been developed. Additional imagery gathering will make land-use monitoring more accurate (Stefanov et al, 2001:174).

Landsat TM imagery is also useful to measure and monitor urban sprawl (Yeh and Li, 2001:84). An analyst can detect changes in urban sprawl by focusing on one geographic area with the help of Landsat TM imagery. For instance, an image from 1990 and an image from 2000 can be compared to detect urban changes. Likewise, geographic regions can be compared to identify areas that exhibit the most extensive sprawl trends. According to Yeh and Li, "This can help government officials and planners to identify the towns that have irrational development patterns" (2001:86).

Urban sprawl has caused environmental problems especially in rapidly growing cities in developing countries (Yeh and Li, 2001:89). Problems include increased sediment and chemical pollutants from new construction that affect water quality in local streams (Bodamer, 2001:7-8). Examination of these problems, revealed by remotely sensed imagery, could provide insight for future city development (Yeh and Li, 2001:89).

With higher spatial resolution such as IKONOS, researchers may obtain greater precision in measuring urban sprawl.

Multi-spectral digital images were used to model the habitat and migratory paths of bird species. Imagery was used in a study to model potential bird strike hazards to U.S. Air Force aircraft. From 1985 to 1993, the Air Force had about 3,200 bird strikes each year. Bird strikes caused the loss of seven airmen, 14 jet aircraft, and over $65 million per year. To prevent further losses, researchers developed a Bird Avoidance Model (BAM) for use by military and civilian pilots. BAM is available through the website, http://bam.geoinsight.com (United States Bird Avoidance Model for Military and Civilian Pilots, 2002). Imagery from the National Oceanic and Atmospheric Administration (NOAA) was used to identify the habitat preference of turkey vultures, a significant source of the bird strike hazard. The researchers analyzed Advanced Very High Resolution Radiometer (AVHRR) imagery to determine vegetation types and land-use patterns in known turkey vulture regions (DeFusco et al, 1993:1481-1487). AVHRR imagery is a multi-spectral digital imagery that has 1.1 x 1.1 km spatial resolution and is collected for the same geographic area every 2 days (Jensen, 2000:205). Through imagery analysis and supplemental field research, the habitat preference and migratory patterns of the birds were identified. With this information, Air Force flight planners can avoid areas that are known to provide excellent habitat for the turkey vulture (DeFusco et al, 1993:1481-1487). Flight planners input parameters of their geographic area and the BAM provides a detailed map of potentially hazardous geographic areas. Flight planners can use this map to plan an alternate route.

Figure 2-22 shows the need for the BAM as birds surround a C-5 aircraft at Dover AFB, Delaware. With the BAM, which incorporates multi-spectral imagery to model habitat requirements and migratory patterns of birds, dangerous situations like bird strikes can be minimized.

Figure 2-22: Bird Strike Hazard to C-5 (United States Bird Avoidance Model for Military and Civilian Pilots, 2002)

Figure 2-23 shows a color-coded relative density of the turkey vulture in the United States during the summer from the BAM. The density was determined in part through the use of multi-spectral imagery. The white lines on the image indicate Department of Defense (DoD) low-level training routes. Areas of concern are where DoD pilots train and vulture density is high.

The relative density of the turkey vulture during the winter from the BAM is shown in Figure 2-24. Note that depending on the time of year, the density of the turkey vulture may be higher in certain geographic areas. The BAM accounts for this by allowing pilots to input the time of year when running the model.

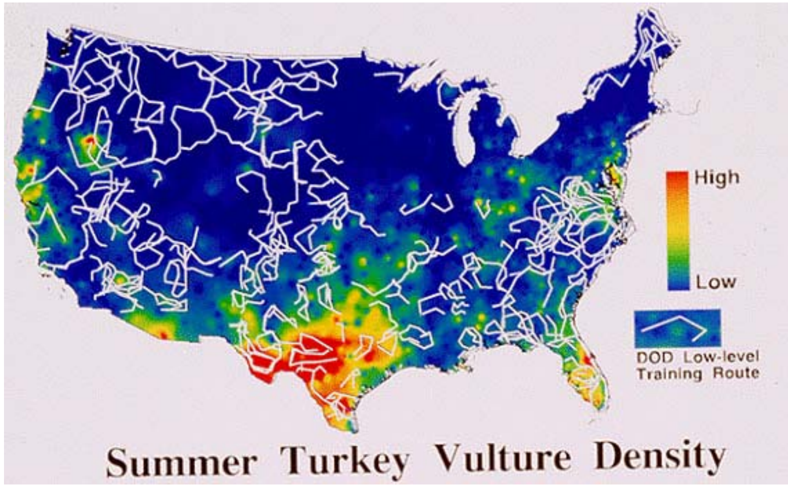


Figure 2-23: Summer Density Map (United States Bird Avoidance Model for Military and Civilian Pilots, 2002)

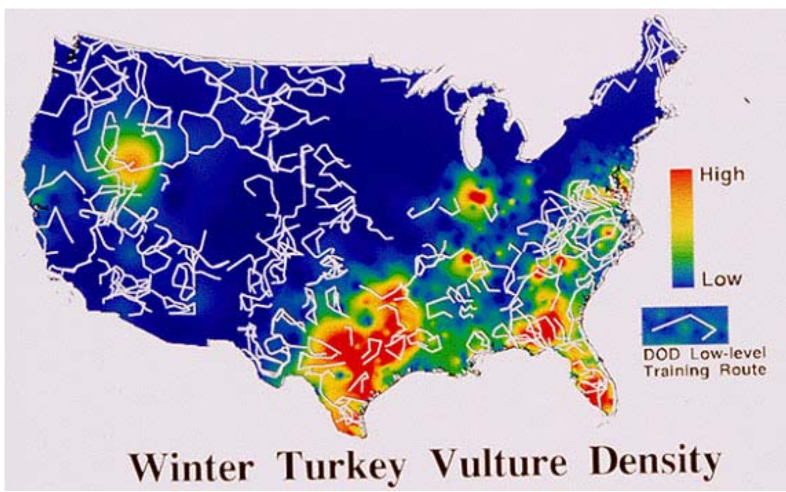


Figure 2-24: Winter Density Map (United States Bird Avoidance Model for Military and Civilian Pilots, 2002)

Figure 2-25 is an example of the BAM output for McChord Air Force Base and surrounding areas. The options selected for this image are military aircrew, July 30-Aug 12 timeframe, daytime flight, and military airfields indicated. The relative risk of a bird strike is indicated on the left side of the image. Low 1, the least risk, is indicated with the bright green color-code and Severe 3, the highest risk, is indicated by the brown color-

code. The map indicates areas that have a higher relative risk of bird strike. For the model parameters selected, the geographic area surrounding McChord AFB is classified as risk level Low 3. The areas to the upper right and lower left of the map identify risk level Moderate 1. A pilot planning this flight route may apply the capabilities of the GIS to avoid a potential bird strike hazard.

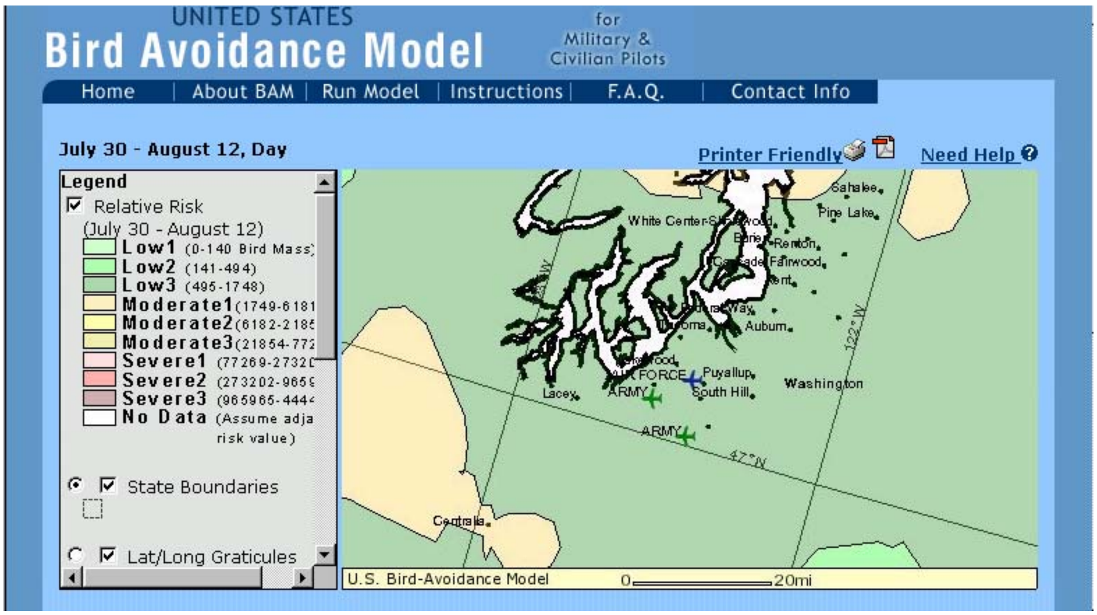


Figure 2-25: Bird Avoidance Model (United States Bird Avoidance Model for Military and Civilian Pilots, 2002)

Advanced sensors mounted to aircraft, similar to those used in satellites, produce aerial multi-spectral images. Satellite images are less expensive, but aerial images via airplane or helicopter may be necessary when adequate satellite data is not available. By using aerial infrared images, areas of vegetation can be easily separated from developed zones. This imagery is used to determine the percentage of vegetation, enabling analysts to predict the amount of runoff in a high rainfall situation. Planners can use this information to improve the storm drainage network and prevent flooding (Vincent et al,

1996:40-41). Presently, newer satellites collect 1-meter or higher resolution imagery from the same geographic area every few days. These images are added to the archives, allowing analysts to access these products at a lower cost.

Landsat TM images have been successfully used to determine the amount of water being used in an arid region. The Landsat TM sensors focus only on the infrared wavelengths. This type of imagery is useful in the analysis of irrigated farmland, preventing expensive surveys. Vegetation returns a bright red reflectance in the near infrared band (Vincent et al, 1996:42-43). These images allow agricultural water consumption to be measured. Analysts can then estimate the capacity of an aquifer in meeting both agricultural and urban population water needs.

Thermal infrared is one section of multi-spectral range that is available on many satellites and aerial platforms, including Landsat TM. Mounted on an aerial platform, the Daedalus brand multi-spectral sensor has 12 spectral bands that collect ground information. One of its spectral bands has thermal imaging capability. The sensor is attached to an aircraft. Spatial resolution of such images varies from one to five meters depending on aircraft altitude (Irvine et al, 1997:1583-1595).

One example illustrates the usefulness of thermal imaging in detecting buried waste. Hazardous chemicals were part of a Department of Energy (DOE) waste site at Oak Ridge National Laboratory. Scientists needed to identify the extent of the buried waste trenches. The trenches were known to contain strontium-90 and cesium-137, chemicals that radiate heat. Map records of the buried waste were destroyed in a fire in 1957, so officials used historical black and white panchromatic imagery of the trench area to establish a general idea of where to conduct thermal mapping. Using this baseline

imagery, a multi-spectral scanner collected a thermal infrared signature from the waste site. The surrounding areas appeared cooler during a nighttime flight and gave the trench area a more pronounced thermal infrared signature. The location of contaminant seepage was identified with 1-2 meter accuracy. Successive ground sampling confirmed contaminant seepage, and measures were put in place for remediation (Irvine et al, 1997:1583-1595).

Air Force planners may apply thermal imagery to detect hazardous waste sites that are located on DoD land**.** Thermal infrared imagery may also be used to identify heat loss from houses and steam pipes.

Figure 2-26 below demonstrates the ability of a thermal infrared sensor to detect thermal pollution of the Savannah River in South Carolina. The river is used to provide water for a cooling tower, with the effluent released back into the river. This image was taken in predawn hours to easily distinguish the river temperatures from surrounding land temperatures. The Savannah River is shown from the top left of the image. The thermal plume from the cooling tower from the top right enters the Savannah River at higher temperatures. White is >20°C above the river ambient temperature as seen in the top center of the thermal plume. Red, orange, yellow, and green are 10.2-20°C, 5.2-10°C, 3.0-5.0°C, and 1.2-2.8°C, respectively, above the river ambient temperature (Jensen, 2000: 271-274).

Hyper-spectral imagery is not covered in the thesis due to time constraints. The decision was made to focus on panchromatic and multi-spectral imagery; and exclude hyper-spectral imagery. Hyper-spectral imagery uses hundreds of spectral bands and is more advanced than multi-spectral imagery. Most multi-spectral imagery systems use

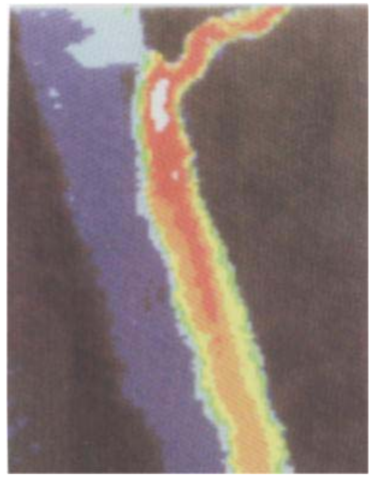


Figure 2-26: Thermal Plume (Jensen, 2000:Plate 8-1)

less than a dozen spectral bands. Hyper-spectral imagery will provide additional capabilities, but it is important for bases to understand the use of panchromatic and multi-spectral aerial and satellite imagery first. Hyper-spectral imagery is a later generation imagery product. Once panchromatic and multi-spectral imagery are implemented, further gains in capability may be achieved with hyper-spectral imagery.

2.4.2 Radar Images

Radar provides the planner with remote sensing information in nearly all-weather conditions day or night. According to Haack and Bechdol, "Radar…has the ability to image through rain, fog, hail, smoke, and most importantly, clouds" (2000:415). Radar provides mapping capability in geographic regions where shorter wavelengths of the electromagnetic spectrum will not work due to poor weather. Early uses of radar provided earth resource mapping for previously unmapped areas due to continuous cloud cover. Most of the available imagery is from Synthetic Aperture Radar (SAR) with aperture referring to a 1-2 meter antenna that is synthesized as a much larger antenna.

The SAR has greater spatial resolution than a real-aperture radar (Jensen, 2000:286). SAR imagery is available from several sources including the U.S. Space Shuttle Imaging Radar (SIR), Canadian RADARSAT, European Space Agency (ERS-1, 2), Japanese Earth Resource Satellite (JERS-1), Soviet Union Almaz-1, and Intermap Star 3*i* (Jensen, 2000:287, 324).

2.4.2.1 Characteristics

Radar is an active remote sensing tool that records reflected signals from microwaves. In active remote sensing, microwaves are generated from the aerial or satellite platform and sensors detect the reflected response. Figure 2-27 shows the wavelengths of radar that are used in remote sensing. These wavelengths are much larger than ultraviolet, visible, and infrared wavelengths. Radar remote sensing systems have various microwave radar wavelengths that are utilized. Figure 2-27 indicates the wavelengths corresponding to each radar band, such as P-band, L-band, S-band, C-band and X-band.

The Shuttle Imaging Radar (SIR) has radar imagery from three different U.S. Space Shuttle missions. These collections of radar imagery coincided with Space Shuttle missions and each collection ended upon return to earth. The three are referred to as SIR-A, SIR-B, and SIR-C, and had durations of 2.5 days, 8 days, and 10 days respectively. In 1978, SIR-A produced L-band wavelength radar images with 40 x 40 meter spatial resolution. In 1984, SIR-B produced radar images also from L-band wavelength with 17 x 25 meter spatial resolution. In 1994, SIR-C produced radar images from X-band, C-band, and L-band wavelengths each with 10-30 x 30 meter spatial resolution (Jensen, 2000:287, 319).

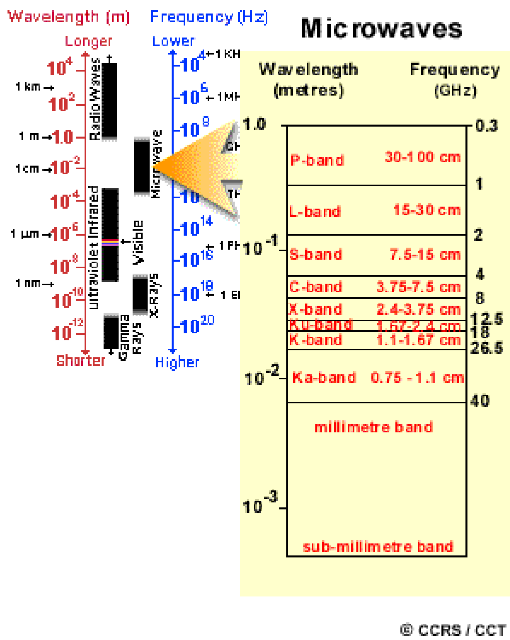


Figure 2-27 Microwave Wavelengths (Fundamentals of Remote Sensing, 2002)

The RADARSAT-1 satellite was launched in 1995 and is still in operation. The radar produces imagery with a C-band wavelength at 10-100 x 10-100 meter spatial resolution. The satellite is in a near-polar orbit that accounts for the range in spatial resolutions. RADARSAT-1 orbits the earth 14 times each day with temporal resolution at 24 days. (Jensen, 2000:287, 319-322).

The ERS-1 was launched in 1991, while ERS-2 was launched in 1995. Both of these radar-imaging satellites are still in operation. ERS-1 and ERS-2 have identical capabilities, each using a C-band wavelength providing 30 x 26 meter spatial resolution (Jensen, 2000:287, 322).

Figure 2-28 is an image from ERS-1 on August 23, 1991 near Bettles, Alaska. The forest fire occurred in 1990, and the Alaska Fire Service estimated the affected area at 116,000 hectares. The area affected by fire is seen as the bright tone in the image. The

bright tone is created where barren ground has higher backscatter than the surrounding forest canopy. The estimated area affected by fire was reassessed at 160,000 hectares with the radar imagery. This value is 38% greater than the original estimate by the Alaska Fire Service (Forest Fires, Interior Alaska, 2002). Managers can use radar to assess the damage due to fires, other natural disasters, and clear-cutting of forests. This can also help managers determine forested areas that may need thinned out because of too much timber biomass.

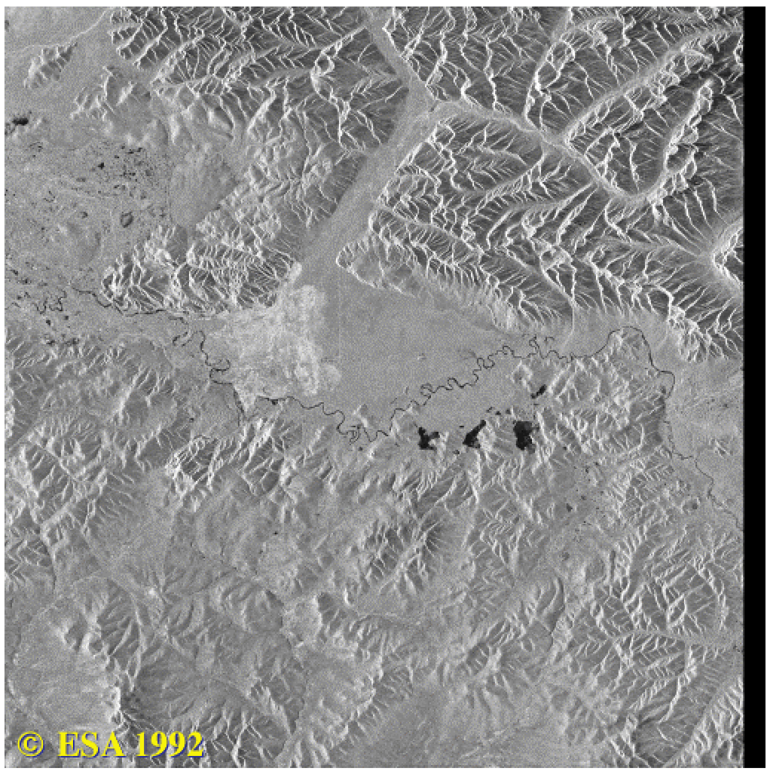


Figure 2-28: ERS-1 Alaska Forest Fire Scarring (Forest Fires, Interior Alaska, 2002)

The JERS-1 was launched in February, 1992 and operated until October 1998. The satellite operated in a near-polar orbit. Radar imagery was produced by L-band wavelength at 18 x 18 meter spatial resolution (Jensen, 2000:287,322).

The Almaz-1 was launched in 1991 and remained in operation for 18 months. Radar imagery was produced using the S-band wavelength. The spatial resolution of the Almaz-1 is 15 x 15-30 meter depending on the geographic location (Jensen, 2000:287, 323).

Star 3*i* provides radar imagery using the X-band wavelength. Spatial resolution is 3 x 3 meter and detailed digital elevation models are available with this high-resolution. The imagery makes it possible to use radar for land-use, land-cover, and watershed hydrologic work (Jensen, 2000:324).

The radar signature of a geographic area depends on the physical properties of the area. An area with a smooth topographic landscape can be measured more easily than one with a rough topographic landscape. Rough landscapes can hide or distort urban features on a radar image (Henderson and Xia, 1997:79-83).

The advantage of using radar is its ability to penetrate cloud-covered regions. The number of cloudy days is higher in some regions than in others. For example, the mean annual number of cloudy days for Phoenix, Arizona is 70 compared to the Seattle-Tacoma area with 226 days (Western Regional Climate Center, 2002). Radar is the only remote sensing technique that can operate effectively during cloudy conditions. Collection may be obtained at any time because radar depends on microwaves, not electromagnetic energy. Radar can detect surface roughness, moisture content, and electrical conductivity of features. As Jensen points out, water and moist soils and vegetation reflect more radar energy than dryer vegetation, soil, and rocks. In radar images, the water and moist soils will be bright with surrounding areas appearing darker (2000:311). Radar is capable of penetrating vegetation, sand, and snow, providing

contours of the land. Radar can also provide spatial resolution as clear as 1 x 1 meter (Jensen, 2000:289).

2.4.2.2 Potential Uses

Radar is useful for "population estimation, assessment of the impact of human activities on the physical environment, mapping and analyzing urban land-use patterns, and interpretation of socioeconomic characteristics" (Henderson and Xia, 1997:79). Population data of cities has historically been conducted through surveys that occur usually every ten years. These surveys have a high cost in terms of time and resources. With radar imagery an accurate and timelier assessment of population can be made (Henderson and Xia, 1997:79-83).

Radar imaging can detect several classes of urban land-use. Radar data is often combined with Landsat TM to obtain greater accuracy (Henderson and Xia, 1997:79-83). Haack and Bechdol add, "By merging optical and radar, an additional portion of the spectrum is available which may improve classification" (2000:412). Radar can effectively enhance the data available through Landsat TM and other multi-spectral imagery.

Radar can aid in the study of social and economic development of communities. The distribution of urban features and the amount of open space can be obtained. By examining radar images, the density of buildings and major transportation routes can also be learned. An experienced radar imagery analyst can interpolate this information to determine social and economic conditions of a city (Henderson and Xia, 1997:79-83).

By assessing the human activity of the physical landscape, planners can determine the need for resources such as health services, and commercial expansion. Planners can

measure urban land-use change over time and use this information to make better decisions. Obtaining this information through traditional methods is more time consuming and costly when planning for large cities (Henderson and Xia, 1997:79-83).

The impact of humans on the environment may be detected through use of radar imagery. Figure 2-29 depicts part of a rainforest in Brazil where clear cutting of trees is evident. Three wavelengths of radar, X-band, C-band, and L-band, produced the three image examples that follow. Each radar band collects varying data about the rain forest. The composite image at the top was generated by computer analysis. The blue and green areas have been cleared for agriculture. The bright pink areas indicate rainforest (Jensen, 2000:315-316).

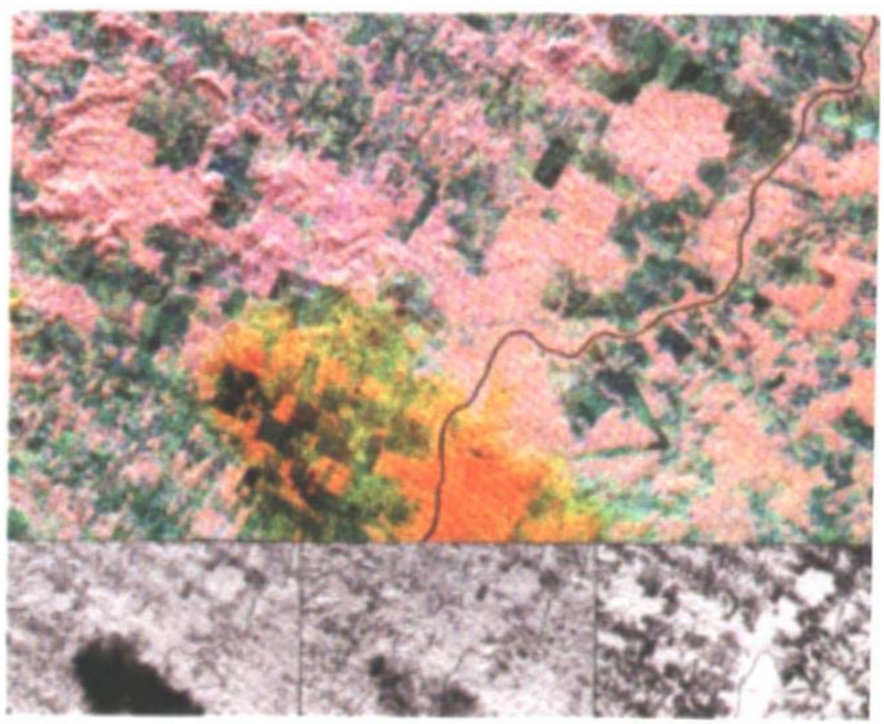


Figure 2-29: Radar Images (Jensen, 2000:Plate 9-2)

2.4.2.3 Radar Limitations

The main limitation of radar is that images are complex and typically difficult to interpret. According to Lillesand and Kiefer,

> Microwave reflections or emissions from earth materials bear no direct relationship to their counterparts in the visible or thermal portions of the spectrum. For example, surfaces that appear 'rough' in the visible portion of the spectrum may be 'smooth' as seen by microwaves. In general, microwave responses afford us a markedly different 'view' of the environment—one far removed from the views experience by sensing light or heat (1994: 648).

The intensity of radar returns is influenced by a variety of factors (Lillesand and Kiefer, 1994: 669). The surface roughness of the geographic area affects the appearance of the radar image (Jensen, 2000:310). Microwave radiation uniquely interacts with vegetation, water, and urban features. Features have unique moisture contents that affect the amount of radar energy reflected back to the sensor.

2.4.3 LiDAR Images

LiDAR (Light Detection and Ranging) uses a laser attached to an airplane to detect the elevation and location of features in a particular geographic area. The laser wavelength used to produce a LiDAR image is 0.90 μm (Jensen, 2000:285). LiDAR has many applications including design of drainage systems and coastal structures, alignment of highways, earthwork projects, modeling flood hazards, determining timely elevation data, and post emergency management. LiDAR is often combined with spectral imagery, such as black and white panchromatic; to provide a product that has horizontal and vertical information (Gutelius: 1998:246-253). LiDAR technology offers an alternative to traditional field surveying or photogrammetry methods of determining feature elevations in two-dimensional imagery. "Photogrammetry is the art and science of

making accurate measurements by means of aerial photography" (Jensen, 2000:137). LiDAR requires less time and personnel training compared to these other techniques.

2.4.3.1 Characteristics

Earth features can be measured with an accuracy of 0.2 meters horizontally and 0.1 meter vertically. LiDAR imagery is a record of the location and elevation of these features. This technique makes data easier to obtain without the need for extensive image analysis (Priestnall et al, 2000:65-68). Photogrammetric image analysis requires multiple images and many man-hours to interpret the data from the photographs. However, using this method, many characteristics can be determined such as precise height, length, area, perimeter, grayscale tone or color, and location of features, as well as photographic scale (Jensen, 2000: 137). According to Jensen, LiDAR makes it easier to obtain these characteristics because "each LiDAR measurement is individually georeferenced" (2000: 327). With LiDAR, characteristics of the aircraft, laser, atmosphere, and earth features of interest are simultaneously recorded resulting in three-dimensional georeferenced coordinates (Jensen, 2000: 327). After the remote sensing information is gathered, processing of LiDAR data can be done easily with a computer. Miotto states, "One advantage of using LiDAR to acquire elevation data is that it radically reduces processing time" (2000:8).

LiDAR imagery can be collected day or night in any geographic region. This is a benefit over surveying of rough terrain (Jensen, 2000: 326-327). Collection is also possible with a minimum amount of cloud cover and precipitation over the area of interest (Broshkevitch, 2002).

2.4.3.2 Potential Uses

Analysts use LiDAR to develop landscape contours, spot heights, building footprints, drainage patterns, watershed delineation, power line detection, and 3-D rendering (Broshkevitch, 2002).

Computer generated landscape contours can be easily created with LiDAR data. The user can designate the contour interval desired with the accuracy of the data as a limit. Figure 2-30 is a contour image developed with LiDAR data. This digital elevation model (DEM) shows the bare earth with trees, buildings, and other aboveground features removed. The image has 1-meter contours.

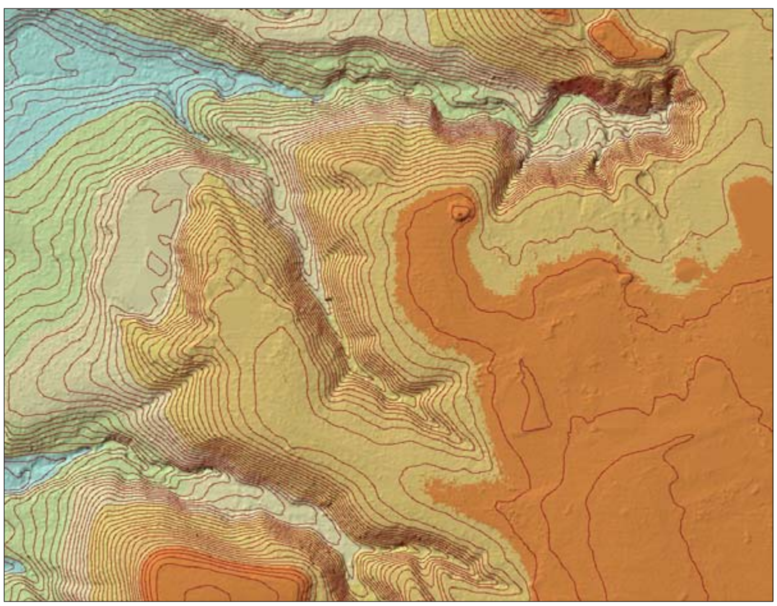


Figure 2-30: LiDAR Contour Image (Broshkevitch, 2002)

Computer generated vegetation images and attributes can be easily created with LiDAR data. Data such as average height, average stem spacing, percent canopy coverage, and vegetation polygon area can be generated. Figure 2-31 is a digital

elevation model (DEM) that shows trees and buildings. A DEM includes data on the elevation and location of each feature in the image. Each tree has a node that links to a database of information with tree height and location. A polygon is drawn, encompassing the trees and allowing analysts to determine the area of canopy coverage.

Figure 2-31: LiDAR Vegetation Capture (Broshkevitch, 2002)

Figure 2-32 shows the attribute data that corresponds to Figure 2-31. The GIS pop-up window shows the data contained in the database for the forest polygon. The database includes information on average height, area of forest coverage, density, and tree stem spacing.

Hydrology modeling is another application using LiDAR data. Figure 2-33 shows the potential drainage, watershed analysis, and flood prediction of the geographic area. The drainage patterns are indicated in dark blue and light blue. The watershed is

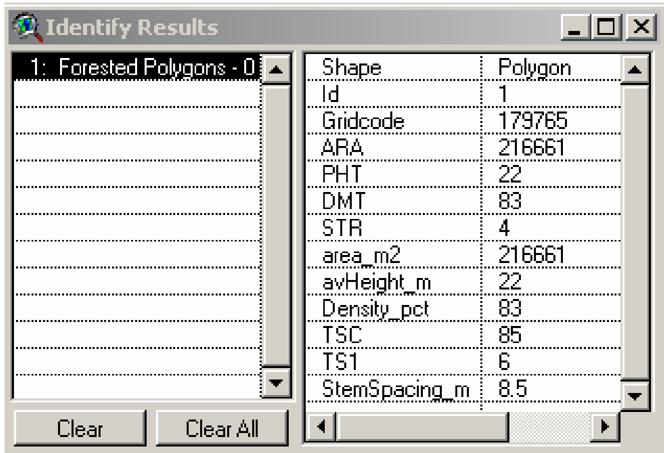


Figure 2-32: LiDAR Attribute Data (Broshkevitch, 2002)

indicated with a polygon shaded green. Potential flooding is indicated in the gray shaded area.

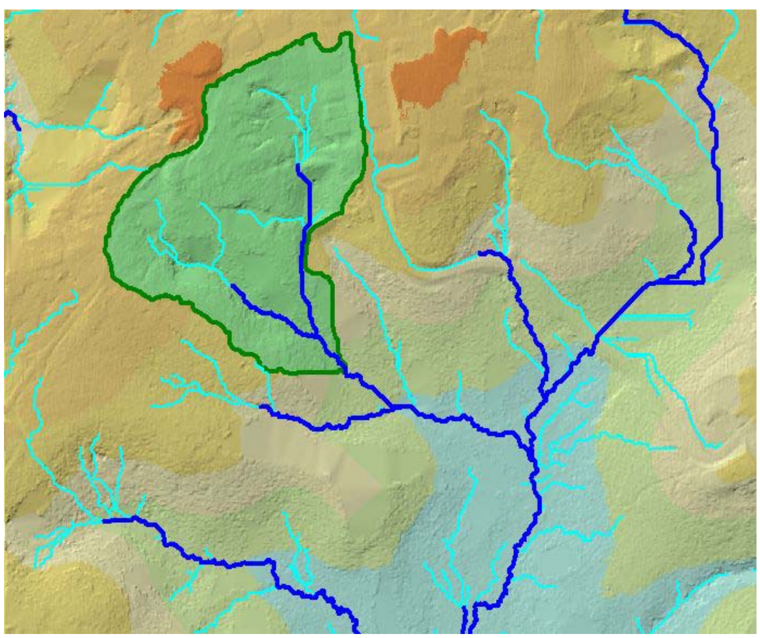


Figure 2-33: LiDAR Hydrology Modeling (Broshkevitch, 2002)

Analysts can easily produce flood hazard models using LiDAR data and computer processing as shown in Figures 2-34 and 2-35. The LiDAR imagery contains elevation

data for man-made features relative to the topography. LiDAR can be modeled in a computer to show the structures at risk during a flood. Planners can then determine what preventative actions to take or where to locate buildings in the future (Priestnall et al, 2000:65-70).

Figures 2-34 and 2-35 are three-dimensional computer simulations of geographic areas that are a high flood risk. Figure 2-34 shows a town along a river without flooding. Figure 2-35 is the same town after a flooding simulation (Priestnall et al, 2000:68). With the aid of these models, planners can design scenarios for evacuation, and preventative-zoning regulations can be implemented.

Figure 2-34: LiDAR Simulation (Priestnall et al., 2000:69)

Three-dimensional images are also possible with LiDAR to show a landscape with buildings and vegetation. Figure 2-36 is useful to planners for determining how changes in vegetation or buildings may affect the geographic area.

Figure 2-35: LiDAR Simulation (Priestnall et al., 2000:69)

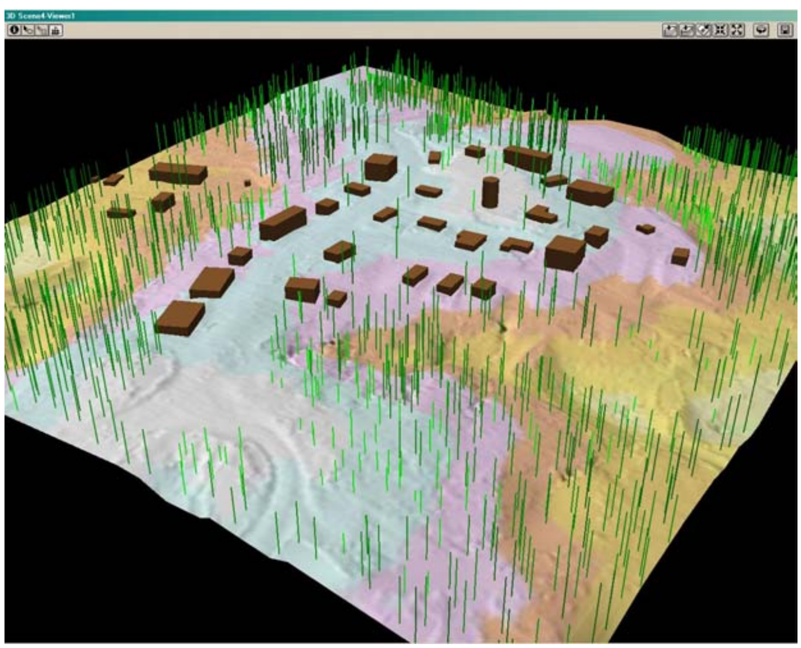


Figure 2-36: Three-Dimensional Image (Broshkevitch, 2002)

As with radar, LiDAR is less sensitive to atmospheric conditions than spectral imagery, and can measure elevations in poor weather conditions. Determining elevations with traditional photogrammetry requires two images of the same geographic area, time,

and training. When Computer Aided Design (CAD) objects are superimposed onto a model that has been developed with the help of LiDAR, the resulting three-dimensional product can be helpful for analysis. Urban planning may be easier using a three-dimensional view (Priestnall et al, 2000:65-68).

LiDAR is valued for its ability to collect accurate laser information in a timely manner and its versatile applicability. When Hurricane Opal struck Florida in 1995, LiDAR was used to map 200 km of shoreline in about two hours. This data was used to produce a computer-generated contour map within two days (Gutelius: 1998:247-249).

Laser remote sensing was used in Moscow to map 5,000 km of transmission lines. This process took only 10 days and achieved 15-20 cm accuracy, outperforming traditional methods of stereo photogrammetry. Furthermore, because expensive fiber optic cable was being installed, LiDAR precision resulted in a greater cost savings for the project (Gutelius: 1998:249).

LiDAR provides 20 cm horizontal and 10 cm vertical accuracy. LiDAR data of large geographic areas can be collected by aerial platform in a timely manner. The data can be used to produce computer-generated models much faster than traditional photogrammetric methods.

2.4.4 Digital Image Availability

Digital Images are available through many government and private sources. Business agreements exist between government entities and private companies to distribute the available images. Private companies often tailor their image products to solve specific problems.

The National Imagery and Mapping Agency (NIMA) should be considered first when acquiring digital imagery. A DoD organization can acquire imagery through NIMA or directly from a commercial company. NIMA has existing imagery license agreements with commercial companies called Indefinite Delivery/Indefinite Quantity (ID/IQ) Government Wide Agency Contracts (GWAC). With these contracts the government can receive discounts for ordering a larger supply of imagery and licensing arrangements. Any United States Government organization can receive imagery from the commercial company by specifying the contract number, but the Government Intelligence Community has priority. Commercial imagery from NIMA comes with many rules on how it can be used. Each user must determine their own needs for the imagery and operate according to the contract and NIMA guidelines (Commercial Imagery Copyright & License Interim Guidance, 2002).

NIMA has imagery available from commercial companies, civil organizations, and foreign commercial companies. Commercial companies include Aerial Images, EarthWatch, ORBIMAGE, Space Imaging, and SPOT Image. Aerial Images provides SPIN-2 imagery. EarthWatch has Quickbird-1, 2; STAR 3i by Intermap; and Russian 1-2 meter imagery. ORBIMAGE has OrbCities; OrbView-2, 3, 4; RADARSAT-1; and SPOT-1, 2, 3, & 4. Space Imaging provides ERS-1, 2; IKONOS; JERS-1; LandSat-4, 5; and RADARSAT-1. SPOT Image has ERS-1, 3; OrbView-2, 3, 4; RADARSAT-1; and SPOT-1, 2, 3, & 4. A government civil organization such as USGS is a source of aerial imagery (Commercial Imagery Copyright & License Interim Guidance, 2002).

2.4.5 Digital Image Cost

NIMA provides commercial imagery to Department of Defense organizations at minimal cost under DoD/Title 50 from their Commercial Satellite Imagery Library (CSIL). In cases where a customer needs imagery not available in the library or needs a broader distribution license for sharing with non-DoD organizations, the customer may have to pay the additional costs. Commercial imagery includes any data that is available on the commercial market including imagery from commercial companies here and abroad, and organizations such as NASA and USGS (Commercial Imagery Copyright & License Interim Guidance, 2002).

2.4.6 Digital Image Limitations

Digital images have limitations in the areas of weather, collection of the appropriate features, high enough resolution for certain applications, satellite imagery system resolution configuration, and cost of on-demand imagery. Each imagery system and type of imagery has limits to the applicability of the imagery to specific requirements.

One of the limitations of LiDAR is that it is weather sensitive. LiDAR sensors are most effective under good weather conditions. Cloud cover will prevent sensors from collecting data about earth features. Vegetation can also be a hindrance. Dense vegetation will impede LiDAR pulses from reaching the ground, preventing analysts from obtaining elevation models and distinguishing features such as buildings from trees (Airborne LIDAR Topographic Surveying, 2002; Jensen, 2000: 329).

There are limitations of digital imagery when obtaining socioeconomic data from an urban landscape. Many socioeconomic characteristics require less than 1-meter spatial

resolution. Newer satellite imagery from IKONOS, Quickbird, and OrvView-3 meet this spatial resolution requirement. However, socioeconomic research, such as a traffic and parking study, requires five to sixty minute temporal resolution. The only imagery source that meets this requirement is a high-cost aerial platform (airplane) or a camera mounted from a high location such as a pole or building (Jensen, 2000: 466-467).

Multi-spectral imagery from sensors such as Landsat TM is configured for a specific spatial, spectral, and temporal resolution. If alternative resolutions are required to solve a given problem, then an aerial platform must be used instead of a satellite platform (Jensen, 2000: 209). Obtaining this on-demand aerial imagery may be more costly as discussed in Section 2.3.6.

III. Methodology

3.0 Introduction

The methodology outlines the process of determining which type of remote sensing imagery, when added to GeoBase, will provide enhanced mission capability. The organization of the methodology is as follows: Set up of a GeoBase Laboratory, Development of an Applications List, Analysis of the information, and Validation. The researcher learned about GIS by setting up a student laboratory, acquiring the necessary hardware to support GIS software, and completing an online course. The Applications List is a compilation of research-backed uses of remote sensing imagery for solving specific requirements. The list was narrowed to only those applications relevant to the Air Force. The analysis process determines how remote sensing imagery can best be applied to various Air Force requirements. Validation of this research and methodology is accomplished by testing the imagery matrix with people at three sample Air Force bases. Three steps are involved in applying the imagery matrix. First, determine the specific imagery that will meet the user's requirements. Second, acquire the appropriate imagery and provide it to validation bases. Third, assess the usefulness of the matrix through feedback from base users, as well as the researcher's observations.

3.1 GeoBase and GIS Learning

GeoBase and Geographic Information System (GIS) concepts need to be understood before imagery solutions can be explored. Several steps were followed to meet this objective including setting up a GeoBase laboratory, progressing through a

professionally recognized training program, and obtaining imagery samples for familiarization.

3.1.1 GeoBase Laboratory

To gain a familiarization with the concept of GeoBase and how to operate a GIS, a computer laboratory was needed. The laboratory must include compatible hardware and software, and Internet capability. A suitable hardware configuration was determined through discussions with GeoBase administrators throughout several Major Commands, as well as obtaining information about the required hardware to operate GIS software and save imagery data.

The computer hardware in the laboratory has the latest capability processing speed and data storage. The computer has a 1.6Ghz processing speed that will enable the timely processing of images. The 40 GB hard-drive provides enough storage space to save data necessary for research purposes. Images require a large amount of data storage space. The computer also has 264 KB of random access memory (RAM). This is essential to the processing speed of the computer. Images also require a large amount of RAM for timely processing. The time it takes to open and manipulate an image depends on the computer's speed and memory. If a user runs multiple applications simultaneously, the computer's processing will be slowed.

Environmental Systems Research Institute, Inc. (ESRI) ArcGIS 8.1 software was used to analyze the imagery in a GIS database. This is a common software program used by many civilian and government organizations. The software is recognized as one of the leading GIS packages available, and has been adopted by many Air Force Bases.

An Internet connection capability was required to access the latest information on GeoBase and GIS, download available imagery, and complete training through an online tutorial. GeoBase program information is accessible through the official GeoBase website. Numerous websites provide an explanation of GIS concepts. Downloading imagery through the Internet is one way to collect data for the GeoBase. Imagery from government agencies and commercial companies can be sent through the mail on a compact disc. The Internet was essential to GIS learning through a website, www.esri.com, determined as the best training alternative for this research.

3.1.2 GIS Training

GIS training may be accomplished in several ways including ESRI online courses; alternative GIS online courses; GIS coursework through local universities; and GIS short courses offered by the Army's Defense Mapping School in Fort Belvoir, VA. ESRI produces the GIS software needed to build a GeoBase, and provides many free courses to Department of Defense employees through the National Imagery and Mapping Agency (NIMA). The online courses are self-paced, and students have up to one year to complete each course upon registration. Self-paced courses allow the student to easily coordinate around other coursework or employment requirements. With an Internet connection and the appropriate software and hardware, the student can learn from any location. The researcher chose this option to further his knowledge about GIS.

The researcher opted to take the GIS course offered by ESRI, despite the availability of other GIS courses, because ESRI was also the designer of the software. This is the same software applied to GeoBase and used by many Air Force installations. ESRI provided data formats such as computer aided drawing (CAD), database tables, and

imagery to learn how to manipulate and use the GIS software. Practice sets of data, exercises, and exams reinforced the material. This training provides a foundation for understanding how imagery is used in a GeoBase program.

Local college classes would require a specific schedule that did not fit well with the timing of this research. Also, the software used at Wright State University was not the latest version, ESRI ArcView 8.1. The University of Cincinnati and Ohio State University would be good options for quality instruction, but they are over 60 miles from the Air Force Institute of Technology. In 1998, the researcher completed a six-week GIS course at the Defense Mapping School, Fort Belvoir, Virginia. The distance and time required to take follow-up courses in Virginia was not practical.

3.2 Air Force Base Applications List

Identifying the Air Force mission applications that will benefit from this research was necessary to develop a useful matrix. This applications list focuses this research on Air Force questions and challenges unique to Air Force operations. Several options for identifying these missions were considered.

3.2.1 Options to Determine Air Force Applications List

An Applications List could have been generated by several sources, including Air Force Mission Statements, existing research through literature review, coordinating with MAJCOM Geo-Integration Officers, and surveys. Mission statements are available for Air Force organizations at all levels from MAJCOMs to the squadrons. Developing a applications requirements list through mission statements would be a time-consuming and inefficient approach, as the researcher would have to gather and breakdown very

broad mission statements into specific activities. This option does not consider creative inputs from personnel in the field. Moreover, Air Force mission statements may not reflect the evolving nature of the GeoBase program.

Literature review provided many imagery applications that could be applied to Air Force problems. These were incorporated into the Applications List. Current literature identified proven civil engineering imagery applications. MAJCOM GIO Officers, who represent a limited group of respondents, could have provided some application inputs based on broad mission requirements. The AF/GIO survey used by the researcher reflects proven as well as potential civil engineering applications. By inquiring at the squadron level, a larger survey group, the researcher gets a more thorough understanding of how people are applying GeoBase in day-to-day operations. Squadron-level personnel who are using GeoBase hands on can provide creative feedback. A survey was selected as the best option because it was the most extensive, encompassing many different squadrons and hundreds of respondents throughout the Air Force.

3.2.2 Air Force Applications List Decision

Science Applications International Corporation (SAIC) conducted a GeoBase survey for the AF/GIO in April 2002. The survey included a section on missions that presently use GeoBase. Survey respondents also indicated potential uses of GeoBase in their jobs to accomplish many varied missions. Information from the survey and the literature review was combined to make a single applications list. This list was used to determine the imagery that is best suited for each application. In most cases, multiple types of imagery are useful to mission accomplishment.

3.3 Analysis

The researcher will analyze how each Air Force application can be aided with the use of imagery. Because multiple sources and types of imagery exist, this research matrix will provide a systematic way to determine the appropriate imagery for each application.

3.3.1 Potential Analysis Methods

Several analysis methods could be used including value-focused thinking, developing a list of all possible applications for a particular imagery type, applying findings from literature, and matching each mission to the appropriate imagery.

In value-focused thinking (VFT), the researcher works with an expert decision maker to determine what factors are important in solving a given problem. These factors must be mutually exclusive and collectively exhaustive. Once these factors are identified, the expert decision-maker assigns a subjective weight (importance) to each factor. For instance, when analyzing imagery to aid missions, the decision maker may identify spatial, spectral, and temporal resolution as factors that are important to choosing the best alternative. The researcher and decision maker then identify possible solution alternatives such as Multi-spectral, LiDAR or Radar imagery. Each alternative is scored against the model hierarchy that was developed. The alternative with the highest score is the best alternative.

The process of identifying the best alternatives can be accomplished with many software applications including FORTRAN or Microsoft Visual Basic. Each of these can be used to develop a software program specifically for determining the appropriate

imagery for each Air Force application. FORTRAN is an older straightforward program, while Visual Basic provides more complex capabilities.

The costs involved for each alternative are considered separately after all the alternatives have been scored. In this thesis, the researcher decided not to use VFT for several reasons. VFT relies heavily on an expert decision-maker to provide subjective weights to the various factors important to the researcher. However, objective remote sensing research is already available that will provide solutions for meeting mission requirements. Often, VFT is used when solution alternatives are not readily known or need to be determined. With imagery, all the possible alternatives are known. The researcher only needs to determine which imagery is best for each mission.

Developing a list of all possible applications for a particular imagery type has unlimited possibilities. This method of analysis would incorporate all available research on imagery applications. Identifying all possible applications for each imagery type would require an unreasonable amount of time. This method was eliminated because it is not specifically relevant to solving Air Force mission problems.

Applying findings from literature review is one way to determine uses for imagery. This method covers many different fields of discipline and applications. Some of the applications gained through literature review are relevant and useful to Air Force problems. These applications are incorporated into the matrix developed in this research.

Matching each mission to the appropriate imagery would provide the most focused and objective way to determine the best use of imagery to solve Air Force problems. This method would include AF/GIO survey information on mission requirements and additional applications from literature review.

3.3.2 Analysis Method Outlined

Matching each application to the appropriate imagery is selected as the method of analysis. Researchers Jensen and Cowen developed Table 3-1 that presents *Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes* (1999). The thesis matrix uses this table as a foundation for analysis. The table identifies urban/suburban attributes and the minimum resolution requirements for each.

The first column in the table is labeled attributes. The attributes are common requirements of organizations such as government planning agencies, the Department of Transportation, utility companies, public service commissions, and the Department of Emergency Management (Jensen and Cowen, 1999:611). For instance, the Department of Transportation often conducts traffic count studies to determine if additional traffic lights are required. Panchromatic or visible aerial imagery acquired every 5-10 minutes, at 0.25-0.5 meter spatial resolution would help planners determine information about a particular intersection. The remaining three columns indicate the minimum resolution requirements for each attribute.

The temporal resolution in Table 3-1 is managerial temporal resolution. The managerial temporal resolution is how frequently managers need new imagery data to fulfill the attribute requirement. For instance, under the category Utility Infrastructure, U1-general utility line mapping and routing would be completed every 1-5 years so managers have current data for these projects.

Jensen and Cowen identify two additional types of temporal resolution, not shown in Table 3-1: urban development cycle and imagery system revisit. The urban development cycle is the evolution of an urban area as the land-use changes over time.

Jensen and Cowen give an example of a housing area that evolved from rangeland to fully landscaped residential housing within one year (1999:611-612). The responsibility to take urban development cycle into account rests with the analyst. Each geographic area has a unique development cycle that must be taken into account during imagery analysis. The development cycle will not be included in the research matrix due to variability of geographic areas. Each analyst must know what development changes have taken place that may not be accurately shown on archived imagery.

The imagery system temporal resolution is how often imagery can be collected of the same geographic area by a satellite or aerial platform (Jensen and Cowen, 1999:614). Aerial collection can be done on demand, weather permitting, providing imagery updates every few minutes as an aircraft passes over the geographic area. Some satellites such as IKONOS and Quickbird provide temporal resolution times of a few days, while others such as Landsat revisit every 16 days. The temporal resolution is crucial to many time sensitive applications such as disaster emergency response. The researcher will identify the remote sensing temporal resolution for each satellite and aerial platform in the research matrix.

Minimum spatial resolution required for each attribute is indicated in Table 3-2. The spatial resolution shown here is the minimum spatial resolution required for the analyst to complete the requirements of the corresponding attribute. For instance, the minimum spatial resolution required for U1-general utility line mapping and routing is 1-30 meters.

Spectral resolution acronyms used in Table 3-2 are shown in Table 3-3. Jensen and Cowen point out that most image analysts would agree that high spatial resolution

(less than 5-meter) is more important that high spectral resolution (multi-spectral capability). Any spectral band will work as long as there is sufficient difference between the feature and the background. There are ideal sections of the electromagnetic spectrum when determining certain information. The ideal spectral wavelengths are indicated for each attribute in Table 3-1 (1999:612-613). For instance, U1-general utility line mapping and routing is ideally accomplished with panchromatic, visible color, or near-infrared imagery.

The main categories have all been highlighted blue in Table 3-1. The category Land-Use/Land-Cover is a United States Geological Survey (USGS) classification system for remote sensing imagery. Land-use indicates the activity for which the land is being used, such as a state park. Land-cover indicates the features on the land such as trees (Jensen and Cowen, 1999:614). The USGS classification system was developed to provide land-cover information using remote sensing data. The classification system has also been used for over 20 years to determine land-use information (Jensen, 2000:414-417). An example of a Level I USGS classification is Urban or Built-up Land. Referring to Table 3-1, L1-USGS Level I, an analyst requires (5-10 year) temporal, (20-100 m) spatial, and (V, NIR, MIR, or Radar) spectral resolution minimums to determine the land-use and land-cover for Urban or Built-up Land. USGS Levels II through IV have higher resolution requirements as shown in Table 3-1.

Table 3-2 defines acronyms used in Jensen and Cowen's table and diagram. This spectral legend is later expanded to include acronyms used by the researcher in the imagery decision matrix and imagery system key.

Table 3-1: Urban/Suburban Attributes and Resolution (Jensen and Cowen, 1999:612).

	Minimum Resolution Requirements		
Attributes	**Temporal**	**Spatial**	**Spectral**
Land-use/Land-Cover			
L1-USGS Level I	5-10 years	20-100 m	V-NIR-MIR-Radar
L2-USGS Level II	5-10 years	5-20 m	V-NIR-MIR-Radar
L3-USGS Level III	3-5 years	1-5 m	Pan-V-NIR-MIR
L4-USGS Level IV	1-3 years	0.25-1 m	Pan
Building and Property Infrastructure			
B1-building perimeter, area, height and cadastral information (property lines)	1-5 years	0.25-0.5 m	Pan-V
Transportation Infrastructure			
T1-general road centerline	1-5 years	1-30 m	Pan-V-NIR
T2-precise road width	1-2 years	0.25-0.5 m	Pan-V
T3-traffic count studies (cars, airplanes, etc.)	5-10 minutes	0.25-0.5 m	Pan-V
T4-parking studies	10-60 minutes	0.25-0.5 m	Pan-V
Utility Infrastructure			
U1-general utility line mapping and routing	1-5 years	1-30 m	Pan-V-NIR
U2-precise utility line width, right-of-way	1-2 years	0.25-0.6 m	Pan-V
U3-location of poles, manholes, substations	1-2 years	0.25-0.6 m	Pan
Digital Elevation Model (DEM) Creation			
D1-large scale DEM	5-10 years	0.25-0.5 m	Pan-V
D2-large scale slope map	5-10 years	0.25-0.5 m	Pan-V
Socioeconomic Characteristics			
S1-local population estimation	5-7 years	0.25-5 m	Pan-V-NIR
S2-regional/national population estimation	5-15 years	5-20 m	Pan-V-NIR
S3-qualtiy of life indicators	5-10 years	0.25-30 m	Pan-V-NIR
Energy Demand and Conservation			
E1-energy demand and production potential	1-5 years	0.25-1 m	Pan-V-NIR
E2-building insulation surveys	1-5 years	1-5 m	TIR
Meteorological Data			
M1-weather prediction	3-25 minutes	1-8 km	V-NIR-TIR
M2-current temperature	3-25 minutes	1-8 km	TIR
M3-clean air and precipitation mode	6-10 minutes	1 km	WSR-88D Radar
M4-severe weather mode	5 minutes	1 km	WSR-88D Radar
M5-monitoring urban heat island effect	12-24 hours	5-30 m	TIR
Critical Environmental Area Assessment			
C1-stable sensitive environments	1-2 years	1-10 m	V-NIR-MIR
C2-dynamic sensitive environments	1-6 months	0.25-2 m	V-NIR-MIR-TIR
Disaster Emergency Response			
DE1-pre-emergency imagery	1-5 years	1-5 m	Pan-V-NIR
DE2-post-emergency imagery	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar
DE3-damaged housing stock	1-2 days	0.25-1 m	Pan-V-NIR
DE4-damaged transportation	1-2 days	0.25-1 m	Pan-V-NIR
DE5-damaged utilities, services	1-2 days	0.25-1 m	Pan-V-NIR

Table 3-2: Spectral Legend

SPECTRAL LEGEND:
Pan=Black and white panchromatic (0.5-0.7μm)
V=visible color (0.4-0.7μm)
NIR=Near-infrared including black and white infrared, color infrared (0.7-1.1μm)
MIR=Mid-infrared including black and white infrared, color infrared (1.5-2.5μm)
TIR=Thermal infrared (3-12μm)
M=Multi-spectral (Includes V, NIR, MIR, and depending on sensor; TIR)
L=Light Detection and Ranging (LiDAR)
Note: LiDAR is used mainly for elevation data; an additional imagery system such as Pan is used to meet the requirements of the mission
WSR-88D Radar=ground-based National Weather Service Weather Surveillance Radar
Radar=Aerial Radar

USGS Level I through Level IV Categories are used in Jensen and Cowen's table. Table 3-3 is an example of the USGS Land-Use/Land-Cover Classification System (Jensen, 2000:416).

Table 3-3 USGS Level I-V (Jensen, 2000:416).

Classification Level	
Level I	1 Urban or Built-up Land
Level II	14 Transportation, Communications, and Utilities
Level III	141 Transportation
Level IV	1411 Roads and Highways
Level V	14111 Dirt
Level V	14112 Paved
Level V	14113 Limited access (freeway, toll)
Level V	14114 Interchange
Level V	14115 Parking
Level V	14116 Bridge

In addition, a Jensen and Cowen developed a figure that shows the imagery that can be used for each attribute. The thesis researcher will transfer the imagery information from the figure to the urban/suburban attributes table. Next, the researcher

will add three more columns to the table: Air Force Mission, Imagery Availability, and Cost.

The Applications List is finalized using the AF/GIO survey and literature review imagery applications. The researcher will identify applications that can logically be consolidated. In the case of missions that cannot be aided by current imagery capabilities, the researcher will list these at the bottom of the table.

The researcher will match the Air Force application to Jensen and Cowen's attributes table. If there is no match, then the mission will be input into the USGS generalized section of the table. Each mission will match to only one attribute. The attributes will have corresponding minimum resolution requirements, imagery type, availability, and cost.

3.4 Validation

Validation is the process of determining the usefulness of the thesis research and whether it can be applied in operational scenarios. Several methods can be used to validate this research, which are described in the next section.

3.4.1 Potential Methods of Validation

The researcher considered four validation methods: field test, MAJCOM/GIO survey, imagery expert survey, and researcher-controlled limited field test. The field-testing method would implement the matrix at various bases and allow users to determine the usefulness of the matrix over time. Because the researcher did not test the matrix in advance, this method involves higher risk. Base personnel, in trying to the implement the unproven matrix, may waste time and money in the form of personnel hours and costly

imagery. MAJCOM/GIO and imagery expert surveys do not provide the broad and varied feedback that would be required for thorough validation. There are remote sensing experts on the thesis committee that provide initial validation. The researcher-controlled limited field test would afford immediate feedback using three Air Force bases. This method is designed to provide a broad range of missions and keep personnel time and cost to a minimum.

3.4.2. Validation Method Chosen- -Researcher Controlled Limited Field Test

The researcher will use civil engineering missions from three active duty Air Force bases. In this scenario, base personnel are more involved in testing the matrix and can provide the researcher with valuable feedback. After the three designated bases have validated the matrix, other Air Force bases may trust it more as a useful tool.
This method can be applied quickly with minimal impact on money and man-hours, and results are prompt. GeoBase is in the implementation phase; therefore an imagery decision tool is needed immediately. Moreover, this method will tackle specific problems without delay.

Three validation bases were chosen based on the following criteria: diversity of missions, in-house GeoBase and GIS expertise, level of GeoBase implementation, and potential for future research coordination. The validation involves two bases from different major commands (MAJCOMs) and one Direct Reporting Unit (DRU): Wright-Patterson Air Force Base, Air Force Material Command (AFMC); Elmendorf Air Force Base, Pacific Air Forces (PACAF); and The United States Air Force Academy (AFA).

Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio has a GeoBase Program that is in an early implementation stage. Because WPAFB is still in the planning

phases, this research will help determine appropriate imagery for mission accomplishment. Wright-Patterson AFB conducts laboratory research and is the Air Force leader in acquisition and development. Aeronautical Systems Center (ASC) is the largest unit at Wright-Patterson Air Force Base with a work force of about 9,000 civilians and military, and an annual budget of nearly $13 billion. Wright-Patterson AFB encompasses 8,357-acres with two runways supporting about 48,000 aircraft operations per year (United States Air Force Fact Sheet: Wright-Patterson Air Force Base, 2002).

PACAF is a leader in implementing the GeoBase program. By choosing a base that already has an operational GeoBase, insight can be gained regarding the usefulness of the research matrix. Elmendorf Air Force Base in Anchorage, Alaska is home of the 3rd Wing, which has 6,700 personnel (Third Wing Mission, 2002).

The United States Air Force Academy in Colorado Springs, Colorado covers 18,500 acres with elevations of up to 7,163 feet. Located at the Academy are special classrooms, labs, and athletic fields for cadet training, and other facilities commonly found on Air Force bases (Air Force Academy Public Affairs Fact Sheet, 2002).

IV. Analysis and Validation

4.0 Introduction

The analysis and validation outlines the actions taken to determine which type of remote sensing imagery, when added to GeoBase, will provide enhanced mission capability. The organization of the analysis and validation follows the same guidelines as outlined in Chapter 3: Set up of a GeoBase Laboratory, GIS Training, development of an Air Force Base Applications List, Analysis, and Validation. Each of these will be discussed in greater detail in the subsequent sections.

4.1 GeoBase and GIS Learning

The idea behind creating a GeoBase laboratory was for specialized training to be conducted on GeoBase and GIS in a focused environment. Two students were working on GeoBase issues and needed a laboratory with necessary hardware and software. Because the field of remote sensing is relatively new to the AFIT schoolhouse, no formal coursework or laboratories existed in-house to support this type of research.

4.1.1 GeoBase Laboratory

The GeoBase Laboratory consists of two high-end computers with appropriate hardware and software capability to support GeoBase research. Computer system requirements were determined based on feedback from Air Force MAJCOM and base-level Geo-Integration Officers about the systems they use to operate their GeoBase. Each computer has a 1.6 GHz processor, 264 Mb RAM, and 40 GB hard-drive. ESRI

ArcView 8.1 software is used for the GeoBase. These computers provided appropriate capability.

ENVI software by Research Systems or Image Analyst software by ESRI should be added to the laboratory computers in the future to take advantage of the data contained in multi-spectral imagery (Frohn, 2002). With ENVI, data is stored on a CD in different spectral bands such as red, green, blue, and near infrared. The imagery spectral bands are manipulated to determine much more detail than is possible with ESRI ArcView 8.1. An image from Image Analyst can provide this analysis as well.

4.1.2 GIS Training

GIS training was obtained through the Environmental Systems Research Institute, Inc. Taking an ESRI ArcView 8.1 introductory course was very helpful in developing GIS knowledge. The self-paced course is taught online at ESRI's website titled ESRI Virtual Campus and can be accessed at http://campus.esri.com/. ESRI provides temporary downloads of ArcView software to use for the course, but ArcView 8.1 was already available to the researcher through AFIT. ESRI courses are available for free from the National Imagery and Mapping Agency (NIMA), with one year allowed to complete the course.

The course was organized into six learning modules: Basics of ArcGIS, Displaying and Geo-referencing Data in ArcGIS, Working with Spatial Data in ArcGIS, Working with Attributes in Arc GIS, Querying your Database in ArcGIS, and Presenting Data in ArcGIS. Each of the modules developed the user's capability to understand how

a GIS is used, reviewed terminology associated with a GIS and ESRI ArcView 8.1 software, and taught how to manipulate a GIS to obtain useful information.

Each of these modules was completed using the ArcView 8.1 software. It was helpful to print out the steps for each module and then work through them because several windows are often open at the same time. ESRI's estimated time for the completion of a module was fairly accurate, taking about 2-4 hours for each, including practice and final tests.

Practice tests reinforced the material, and a final examination was given at the end of each module. The exams were straightforward and tested the ability of the student to manipulate the software program to obtain answers using practice data sets. A score is calculated that determines whether the student can advance to the next module. A 70 percent score is required to proceed to successive modules. Students can review their answers and the tutorial and retake the exam if necessary. A benefit to the online course is that it is self-paced, which gives the student flexibility.

In addition to reviewing GIS fundamentals, the researcher needed to acquire imagery to further develop an understanding of current imagery of an Air Force base. One of the Air Force bases used for validation had imagery readily available. The purpose was to test the software capability and aid the researcher in understanding strengths and limitations of the imagery. IKONOS imagery of the United States Air Force Academy (USAFA) demonstrated the impressive capability possible at 1-meter resolution (Portillo, 2002).

The researcher's efforts to understand imagery and the capabilities of ESRI ArcView 8.1 had a positive result. The Internet tutorial provided a foundation for

understanding how data is used and manipulated in a GIS. By understanding how a GIS works, and practicing with actual current imagery from an Air Force base, the researcher developed an adequate familiarization that was valuable to the thesis effort.

4.2 Air Force Base Applications List

Developing the Applications List involved assimilating information from three major sources including research from literature review, AF/GIO survey results from April 2002, and insights from a 2002 Geospatial Technologies Symposium & Exposition. Some examples of imagery applications identified in the literature review and from the AF/GIO survey are shown in Table 4-1. There were many applications identified in the literature review that addressed many of the application concerns in the AF/GIO survey. The AF/GIO survey did not detail how imagery is used in GeoBase, but the requirements of GeoBase imagery logically matched the applications identified in the literature review in most cases. Seven additional applications were identified in the AF/GIO survey and are discussed in more detail later in this section. More than 50 applications were identified that are relevant to Air Force missions. These applications range from urban infrastructure to natural resources management. The complete list of applications is available in Column 1 of Appendix B, Imagery Decision Matrix.

The AF/GIO survey of Air Force GeoBase applications was reviewed for appropriate Air Force mission applications. Eighty-five main operating bases responded to the survey. There were more than 100 responses regarding GeoBase applications from individual squadrons. The survey was formatted for data entry in several areas including Air Force base survey identification number, characteristics about the application,

contractors involved in implementing the application, and compliance with spatial data standards. The application description was used for applications included in the

Table 4-1: Air Force Applications List Examples

Distance and area measurements, building footprints
Facility elevations
Community planning
Population estimation
Urban sprawl
Transportation management (repairs)
Traffic studies (parking; conjested areas)
Digging Permits (site information)
Highway alignment planning
Forest management(deciduous, evergreen, or mixed identification)
Clear-cut forest identification
Environmental hazards Identification
Fire Response GPS/GIS Tracking System
Fire Management

Applications List. Applications of GeoBase ranged from infrastructure measurements and management to wartime training and tasks.

Table 4-2 contains some examples of applications provided by the survey. The responses shown indicate an open-format style format. Each of the applications was reviewed to determine if imagery could enhance the user's ability to accomplish the requirement. For instance, the first application shown in Table 4-2 is urban forest database. This application is accounted for in the Forest management section of the Applications List.

The second application listed in the survey indicates water, sewer, storm water sewer coverage loader. Additional information is provided for some of the applications such as, set edits environment, which is not important to determining imagery

applications for GeoBase. This application is incorporated under Facility management and Flood prevention and planning tool in the Applications List.

Some survey applications had no direct correlation to the use of imagery. The next application listed, ArcView map production extension, is an example of an application that was not incorporated into the Applications List. This application is simply a computer application that is not relevant to determining an Applications List. Many of the applications identified on the AF/GIO survey from April 2002 were already accounted for through literature review. Several more had no relevance to the Applications List developed. Several new applications were identified from the information provided in the survey. A discussion of these follows.

Table 4-2: GeoBase Application Examples (AF/GIO survey, 2002).

urban forest database
Water, sewer, stormwater sewer coverage loader, set edits environment
ArcView map production extension
Arc/Access interface to query airfield obstructions
environmental restoration application
NEPA environmental assessment application
A file manager with tool to retrieve and group themes. it also connects themes to database and legend files.
Tool that edits shapefiles.
Geospatial Event Response System - Used basewide for planning and initiating responses to emergency events.
Customized application, used to provide basewide access to CIP.
Application built with purpose of integrating data sources such as other mission databases outside the CIP.
Application built with the purpose of accessing quick and easy maps of the installation, with some query ability.
Fire Department application which integrates the CIP with the ACES-FD module. Ties event information to the map.
Application used to identify UXO hazard areas and monitor clearance actions. Will have access from the Web in the future.
Used to manage mobile and static target status, condition and location. Will have access from the Web in the future.
Used to track profile utilization rate and thus better manage the siting of future range assets. Will have access from the Web in the future.
Used to plan and track the maintenance of Reservation roads and gates in support of missions. Will have access from the Web in the future.
Smoke modeling for Wildland & Urban Interface Fire Management

Seven new applications were identified from the survey. The seven applications include aircraft accident investigations, asbestos identification, noise contour mapping, Rapid Runway and Repair (RRR)/Minimum Operating Strip (MOS) operations, Unexploded Ordinance (UXO) identification, mapping of airborne chemical plumes, and target asset management.

Aircraft accident investigation is possible with imagery available commercially and was added to the Air Force Applications List. Asbestos identification and noise contour mapping require further imagery research to determine if these are possible. These are included in the Applications List with the note (Future application). With satellite advances, these two imagery applications may be possible in the future.

Rapid Runway and Repair (RRR)/Minimum Operating Strip (MOS) operations, Unexploded Ordinance (UXO) identification, mapping of airborne chemical plumes, and target asset management were not included in the Applications List because these are assumed to be wartime requirements. Additionally, airborne chemical plumes can not be detected with the imagery researched, but may be possible with hyper-spectral imagery discussed later in Section 5.4, Future Research. Wartime requirements will have classified imagery to exploit with more capability than imagery systems researched for this thesis. Additionally, many of the recommendations for collecting aerial imagery will be unique because of the high-risk to aircraft. Aircraft may be at risk of attack when flying within the range of surface to air missiles and anti-aircraft artillery in a war zone. For this reason, war zone remote sensing aerial platforms need to operate at a much higher altitude than for peacetime collection. The Air Force GeoReach program should incorporate these applications into a decision tool for wartime purposes.

The survey findings presented several challenges and limitations. Many responses provided minimal explanation, and the survey results concerning applications came from only 35 of the 85 participating bases. The data was limited in that only Air Force Civil Engineer (CE) personnel completed the survey, rather than several squadrons on each base. According to AF/GIO, future GeoBase surveys would include many more participating squadrons. Despite the limitations, the survey still provides insight into GeoBase applications.

The 2002 Geospatial Technologies Symposium & Exposition confirmed the applications found in the literature review and their relevance to Air Force requirements. Applications presented on various military and civilian projects provided further

understanding of GIS and the appropriate uses of imagery. One application presented on LiDAR significantly helped in understanding the products available with LiDAR data. LiDAR is discussed in more detail in Chapter 2.

A comprehensive Air Force Applications List was developed from the literature review, AF/GIO survey, and the 2002 Geospatial Technologies Symposium & Exposition The list includes more than 50 imagery applications that can benefit GeoBase, and these are shown in the Imagery Decision Matrix, Appendix B.

4.3 Analysis

The analysis method is explained and then five sub-sections of the analysis are discussed including Jensen and Cowen's table and diagram used as a foundation for the decision matrix, an initial and final version of the imagery decision matrix, and an initial and final version of the Imagery System Key. Jensen and Cowen developed a table and diagram for identifying the minimum imagery required to meet particular urban and suburban requirements shown in Section 3.3.2. Their work was used as a starting point for developing a decision tool to determine particular imagery types best suited for specific Air Force applications. An initial imagery decision matrix and imagery system key was developed from the literature review and Jensen and Cowen's table and diagram. Later, significant revisions to the matrix and key were made which streamlined the decision process and made the tool more user-friendly. Each of these sections will be discussed in more detail to follow.

4.3.1 Analysis Method

Microsoft Excel spreadsheet software was used to create an imagery decision matrix. Before building the spreadsheet, urban and suburban applications of remote sensing imagery were reviewed (Jensen and Cowen, 1999). Jensen and Cowen's information contained in a table and diagram, presented imagery applications for managers to use in decisions concerning infrastructure, environmental management, socioeconomic characteristics, and emergency response. Jensen and Cowen's table is shown in Table 3-1. Jensen and Cowen's diagram, shown in Figure 4-1, is used with the table to determine the current remote sensing systems that can fulfill the attribute requirements outlined in the table. Information was combined from both the table and Figure 4-1 into one spreadsheet, the imagery decision matrix. This reduced the level of complexity posed by the original table and Figure 4-1, and was the first in a series of steps to develop an imagery decision matrix for Air Force GeoBase.

4.3.2 Jensen and Cowen Table and Diagram Foundation

There are several reasons to use Jensen and Cowen's research as a starting point for developing the imagery decision matrix. The table and diagram present a significant amount detail that is useful to this research. Furthermore, the urban and suburban attributes represented in Jensen and Cowen's table have many similarities to Air Force base applications. Even with the foundation provided by Jensen and Cowen's table and diagram, many formatting and content improvements were made to tailor the information into an Air Force imagery decision matrix. The discussion that follows provides further details about Jensen and Cowen's diagram.

Jensen and Cowen's diagram that is used with Table 3-1 is shown in Figure 4-1. The x-axis represents nominal spatial resolution (meters), and the y-axis represents temporal resolution (minutes). To use the diagram, first identify an urban/suburban attribute code listed in Table 3-1, such as C2-dynamic sensitive environments. C2-dynamic sensitive environments require a minimum temporal resolution range of 1-6 months and a minimum spatial resolution range of 0.25 to 2 meters. A manager can obtain imagery with one of the minimum spectral resolutions required noted as visible, near infrared, mid infrared, or thermal infrared to fulfill requirements of the dynamic sensitive environments attribute.

The C2 ellipse is located in the upper left portion of Figure 4-1. Many shaded rectangles are included on the diagram. Each of these represents an imagery system such as aerial imagery, Quickbird, IKONOS, and others. Jensen and Cowen use arrows to point to a rectangle with an adjacent list of imagery systems. The rectangles fill in the area of the graph for the spatial and temporal resolution of each imagery system. The area of the graph (Figure 4-1) covered by a rectangle represents the spatial (x-axis) and temporal (y-axis) resolution capability of each imagery system. Attributes presented in Jensen and Cowen's table (ellipses) are overlaid onto imagery systems (rectangles) that represent temporal and spatial resolution. The minimum spatial and temporal resolution requirements of C2-dynamic sensitive environments are fulfilled by aerial imagery because it is superimposed over top of the rectangle representing aerial imagery. A user of this diagram must also envision that the ellipses may be shifted side to side and up and down, overlapping different rectangles. Hence, more than one imagery system will provide for the minimum resolution requirements of C2-dynamic sensitive environments.

Rectangles that have either lower (more precise) spatial resolution and/or lower (less time required) temporal resolution will also fulfill the requirements. In the case of C2, Quickbird and Space Imaging IKONOS are applicable. This is demonstrated by shifting the C-2 ellipse downward. The imagery systems Quickbird and IKONOS are intersected by the C-2 ellipse, therefore they also will fulfill the requirements of C2.

Because the diagram is visually complex, both the table and diagram were combined into one simplified imagery decision matrix. This allows a manager to determine the appropriate imagery for a particular application all in a spreadsheet format.

Jensen and Cowen's table formed an initial framework for the matrix, and an additional column was added for imagery systems represented in the diagram, as well as those researched through literature review. A discussion of the construction of the imagery decision matrix follows.

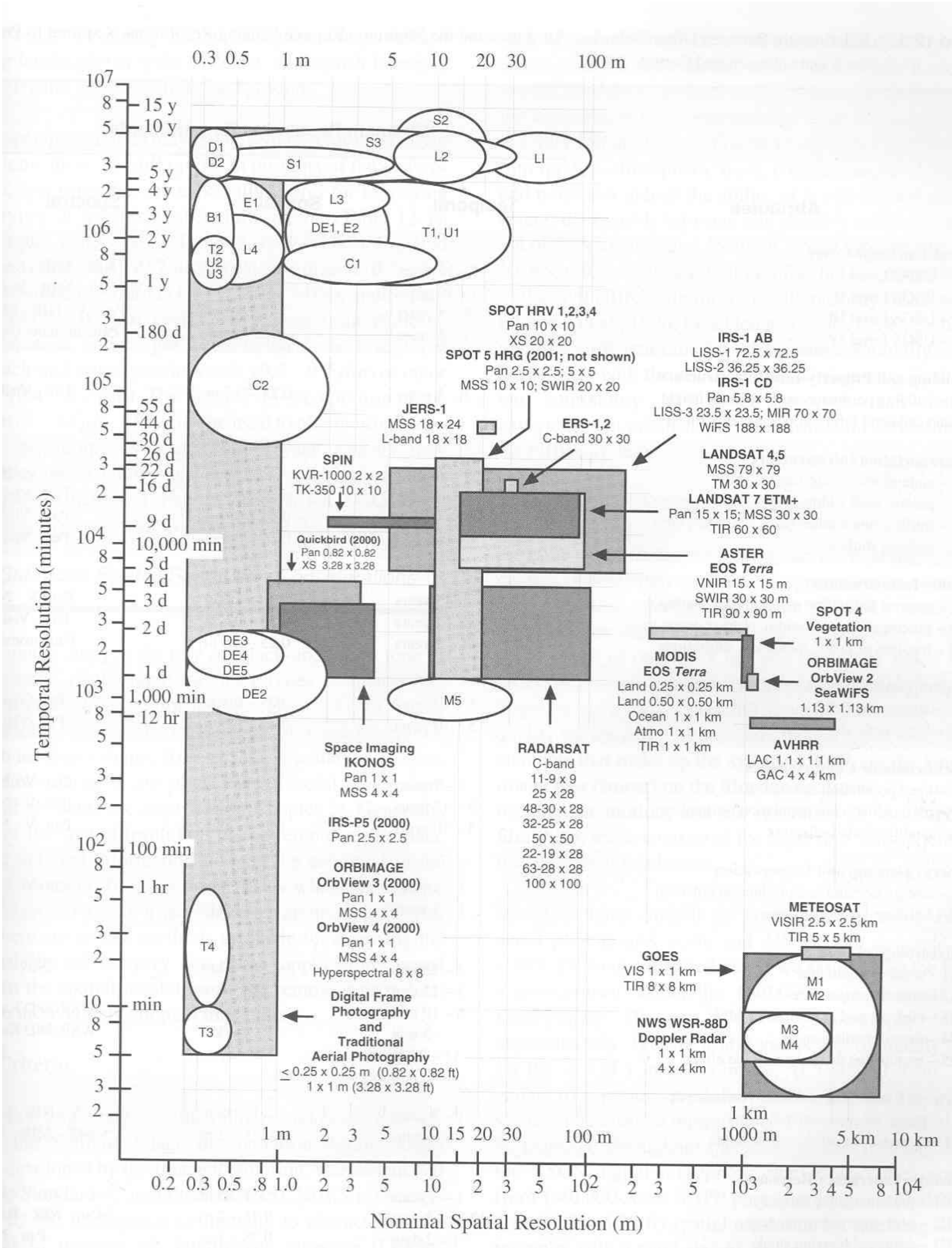


Figure 4-1: Diagram of Resolutions (Jensen and Cowen, 1999:613).

4.3.3 Imagery Decision Matrix - Initial

The Imagery Decision Matrix is used to determine what type(s) of remote sensing imagery are applicable for a specific Air Force requirement. Many different formats are possible to display information contained in the imagery decision matrix. There are multiple ways to combine applications, imagery, and resolutions. The format presented here represents an optimum way to view and use the information. In order to minimize the difficulty in using the imagery decision matrix, an imagery system key and instruction sheet were developed. These are discussed in later sections. The final version of the imagery decision matrix and imagery system key is presented in later sections, however, demonstrating the initial formats shows how this tool evolved. The initial imagery decision matrix is shown in Appendix A. The matrix can be used to determine the imagery that best suits a specific task or as an educational tool to learn about the imagery types and capabilities that are available. The imagery decision matrix consists of seven columns, which are discussed in greater detail.

Column 1 includes Air Force applications that were identified according to Section 4.2 and were matched to the attributes in Column 2 from the Jensen and Cowen table. Some applications and attributes were easy to match such as traffic studies and T3-traffic count studies (cars, airplanes, etc.). Other applications were not as easily matched to an attribute. The distance and area measurements application was matched to the B-1-building perimeter, area, height and cadastral information (property lines) attribute. This was a logical position for the distance and area measurements application, although it could have been placed under more than one attribute or a different attribute such as U2-precise utility line width, right-of-way. Table 4-3 shows examples of the Air Force

applications and attributes contained in the imagery decision matrix that were matched to the B-1 attribute.

Column 2 is the attributes column from Jensen and Cowen's table. The attributes are identified according to sub-headings such as Land-Use/Land-Cover and Building and Property Infrastructure. Under each sub-heading, there may be one or more categories. For example, under the Land-Use/Land-Cover subheading, there are four categories: L1 through L4 corresponding to USGS Level I-IV. The United States Geological Survey (USGS) Levels I-IV are classifications, first devised in the 1970s, that indicate the capability of a remote sensing image. The USGS classification system matches specific land-use and land-cover with remote sensor data characteristics. Table 4-3 is an example of information in the attributes column for B1-building perimeter, area, height and cadastral information.

Table 4-3: Applications

Table 1.	
Imagery Decision Matrix-Initial	
1. Applications	**2. Attributes**
	Building and Property Infrastructure
Distance and area measurements	B1-building perimeter, area, height and cadastral information (property lines)
Digging Permits	
Community planning	
Building footprints	
Spot heights	
Facility elevations	
3-dimensional rendering	
Facility management	

Column 3, temporal resolution, identifies the amount of time that imagery data can be used before updated imagery is necessary. This takes into account the timeliness of the imagery for a given application. For instance, if distance and area measurements are needed, then the imagery should be updated every one to five years at a minimum. Table 4-4 is an example of the temporal, spatial, and spectral resolution columns.

Table 4-4: Minimum Resolution Requirements

Minimum Resolution Requirements		
3. Temporal	**4. Spatial**	**5. Spectral**
1-5 years	0.25-0.5 m	Pan-V-*LiDAR*

Column 4 represents the minimum spatial resolution that is necessary for an analyst to use for a particular application. For instance, a 1 x 1 meter spatial resolution image will allow an analyst to determine information about features that are 2 x 2 meter in size or larger. Spatial resolution is reviewed in Section 2.3 of the thesis. A 0.25-0.5 spatial resolution is the minimum requirement for this particular application.

Column 5, spectral resolution, is the minimum requirement for an analyst to determine information from an image for distance and area measurements. Therefore, an analyst can use panchromatic, visible, or LiDAR imagery to obtain distance and area measurements. Multi-spectral imagery will not provide any additional information necessary to make distance and area measurements. Radar will not provide high enough spatial resolution to make distance and area measurements. Various parts of the electromagnetic spectrum that an imagery system may ‘see’ include ultraviolet; visible green, blue, and red; near infrared; mid-infrared; thermal infrared; radar; and laser. The

spectral resolution capability of each remote sensing system varies. For example, the sensor onboard the Quickbird satellite can 'see' ultraviolet; visible green, blue, and red; near-infrared, and mid-infrared wavelengths of the electromagnetic spectrum. Quickbird uses these wavelengths to produce imagery. An example of the spectral resolution is shown in Table 4-4. The panchromatic (Pan) and visible (V) wavelengths are minimum spectral resolution requirements for this application. LiDAR, indicated in italics, is a recommendation added by the researcher. LiDAR was not included in the original spectral resolution Jensen and Cowen table because it is not a minimum requirement. LiDAR provides elevation analysis capability.

Column 6 lists imagery systems identified by the researcher that will meet or exceed the minimum managerial temporal, spatial, and spectral resolution requirements. Table 4-5 shows examples of the imagery systems in the matrix. An explanation of the capabilities of each of these is included in Chapter 2 and in the imagery system key.

Table 4-5: Imagery System

6. Imagery System
Aerial Photography
Quickbird
IKONOS
OrbView 3/4
SPIN 2.
SPOT 5
IRS-P5
Landsat 4,5,7
JERS-1
RADARSAT
ERS-1,2.

Column 7 indicates notes about each imagery application. This column points out any special circumstances for the use of the imagery. For instance, the application of environmental hazards identification has comments in the notes column as shown in Table 4-6. Column 6 identified the imagery systems that would fulfill requirements of the application. Several imagery systems have multiple sensors that produce different types of imagery. For instance IKONOS and Quickbird imagery systems produce both panchromatic and multi-spectral imagery, and each type has differing characteristics of spatial resolution. The spatial resolution requirement for the environmental hazards application is 0.25-2 meters. IKONOS and Quickbird panchromatic imagery fulfill this requirement, however IKONOS and Quickbird multi-spectral imagery do not. The notes column indicates this information.

Table 4-6: Notes

7. Notes
Panchromatic only for IKONOS and Quickbird

Several imagery characteristics were initially considered, but not incorporated into the final matrix. These characteristics include ease of use, image file size, processing time, and cost per image. Ease of use, or a measure of how easy the imagery is to work with, was not used in the final matrix because the training hours required would vary widely from one person to another. Because there are many different formats possible for imagery, file size was not an included characteristic. The researcher assumed that the computer used by GeoBase personnel would be capable of handling any file sizes

without difficulty. Processing time was not included in analysis because GeoBase computers should have adequate processors to handle the imagery. Cost per image was not included because this is subject to change, and there are many cost structures depending on the format of the imagery. Also, in many cases, imagery at minimal cost is available to government agencies. Availability of the imagery was moved to the imagery system key because this information is not needed to make a decision about what type of imagery to obtain for an application.

4.3.4 Imagery Decision Matrix - Final

The final format of the imagery decision matrix is shown in Appendix B. The format of the initial imagery decision matrix was difficult to use, making it necessary to create a more streamlined tool. The final imagery decision matrix maintains all of the information of the initial matrix, while providing a more user-friendly organization.

Column 1, Applications, is now a combination of the applications and attributes columns from the initial imagery decision matrix. A difficulty with the initial matrix was that applications and attributes did not provide a perfect match. For instance, in the initial imagery decision matrix, powerline detection was matched to U-1-general utility line mapping and routing. New applications were developed using USGS classifications (Jensen, 2000:413-416). In the final matrix, powerline detection is part of transportation, airfield, communications, and utilities, a broader application heading. Some applications were grouped under the following headings: Multiple Categories, Emergency Actions, and General Topographic Data.

Table 4-7 shows the applications column of the final matrix. Combining the applications and attributes into one column makes the matrix easier to read and use.

Major categories identify features such as urban or built-up land, agriculture, rangeland, forest, water, and wetland. Applications that fit multiple categories are listed at the end of the matrix. Under each major category, applications are organized displaying successively stricter imagery resolution requirements. For instance, in Table 4-7, urban or built-up land has the lowest resolution requirements. Residential area delineation, the next application, requires higher resolution imagery to fulfill requirements. Single-family residential identification requires even higher resolution, and the next five applications listed in Table 4-7 require the highest resolution. All applications in the imagery decision matrix are grouped into one of four categories depending on the level of imagery resolution required. The category code can also be seen in Column 5, imagery systems, which will be discussed later in this section. The particular resolutions will be discussed further with an explanation of each data column contained in the imagery decision matrix shown in Appendix B.

The list of applications is not all-inclusive, yet provides a solid foundation of applications for use in GeoBase. Several applications such as distance and area measurements and community planning could be listed under different major categories. They are listed once for simplicity and arranged under the most logical major category.

Column 2, Temporal Resolution, identifies the minimum requirement for each application listed. The imagery decision matrix is shown in Appendix B. The data in the imagery decision matrix corresponding to the applications shown in Table 4-7 will be presented next. Table 4-8 is the temporal resolution for the applications shown in Table 4-7. The temporal resolution shown represents the refresh time that managers of imagery typically need to acquire new imagery to maintain current information. Note

that the category level of a particular application is independent of the temporal resolution for the application. Several category 4 applications suggest that a temporal resolution of 1-5 years is necessary, while several others recommend a temporal resolution of 5-7 years.

Table 4-7: Applications Column

Imagery Decision Matrix
1. Applications
Urban or built-up land identification
Residential areas delineated
Single family residential identified
Distance and area measurements, building footprints
Facility elevations
Community planning
Population estimation
Urban sprawl

Column 3, Spatial Resolution, indicates information as explained in the initial imagery decision matrix. Spatial resolution in Table 4-13 is shown for the applications in Table 4-11.

Column 4, Spectral Resolution, contains information as discussed in the initial imagery decision matrix. Table 4-14 contains the data for the applications shown in Table 4-11.

Column 5, Imagery Systems, contains the category code for the imagery systems according to USGS classifications. The category codes were created to make the matrix easier to use. Each of these categories was determined by USGS spatial resolution guidelines. Category 1 identifies the lowest capability, whereas Category 4 indicates the

highest capability. Figure 4-15 indicates the category codes for the applications shown in Table 4-11.

Table 4-8: Minimum Temporal, Spatial, Spectral Resolution; and Imagery Systems

Minimum Resolution Requirements			5. Imagery
2. Temporal	**3. Spatial**	**4. Spectral**	**Systems**
5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
5-10 years	5-20 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 2
3-5 years	1-5 m	Pan-V-NIR-MIR-*M-LiDAR*	Category 3
1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
5-7 years	0.25-5 m	Pan-V-NIR-*Radar-LiDAR*	Category 4
5-7 years	0.25-5 m	Pan-V-NIR-*Radar-LiDAR*	Category 4

The minimum resolution requirements were identified as subjective depending on the user's experience, equipment and other conditions. For instance, fairly accurate distance and area measurements are possible with 1-meter spatial resolution imagery rather than the 0.25 to 0.5-meter spatial resolution suggested by the matrix (Frohn, 2002). Instead of identifying all imagery systems that meet the requirements of each application, an application is grouped into a category based on USGS classifications.

A single-source imagery recommendation for each application was not created. In the initial matrix, an additional column was added for recommended imagery for each application. This determination was based upon spatial, spectral and temporal resolution requirements. A further consideration was to limit the number of imagery systems represented to minimize the requirement on Air Force GIOs to obtain, manage, and update a large number of imagery types. In the initial imagery matrix, government imagery sources at minimal cost were given priority of selection over commercial sources

of imagery. Therefore, if two imagery systems fulfilled the requirements the government imagery system was recommended. Recommended imagery column is not presented in the final imagery decision matrix to give the manager more choice in determining the appropriate imagery for a specific application.

4.3.5 Imagery System Key - Initial

The Imagery System Key is used in conjunction with the Imagery Decision Matrix to provide additional information on each imagery system. Two versions of an Imagery System Key were developed. The initial Imagery System Key is presented here to demonstrate the initial format and show how the key evolved. The initial Imagery System Key is as a reference, whereas the final Imagery System Key is used by the manager in deciding the final imagery system for a particular application.

The imagery decision matrix became too large to provide information in a user-friendly format. A second table, the imagery system key, was developed to streamline the imagery system matrix. The key also details the pertinent characteristics of each imagery system. The imagery system key is shown in Appendix C.

The key has a spectral legend at the top explaining acronyms used throughout the key and imagery system matrix. The spectral legend has a note at the bottom outlining the use of italics in the matrix and key. Italics are used in the spectral resolution column, indicating additional imagery system spectral resolutions that fulfill the requirements of the application. For instance, for distance and area measurements, LiDAR will provide information to make area measurements. This type of imagery was not presented in Jensen and Cowen's original table, but will be useful for this application. The spectral legend is shown in Table 4-9.

Table 4-9: Spectral Legend from Imagery System Key

Table 2.	
Imagery System Key-Initial	Pan=Black and white panchromatic(0.5-0.7µm)
	V=visible color(0.4-0.7µm)
SPECTRAL LEGEND:	NIR=Near-infrared including black and white infrared, color infrared (0.7-1.1µm)
	MIR=Mid-infrared including black and white infrared, color infrared(1.5-2.5µm)
	TIR=Thermal infrared(3-12µm)
	M=Multi-spectral (Includes V, NIR,MIR, and depending on sensor;
	L=Light Detection and Ranging (LiDAR)
	Note: LiDAR is used mainly for elevation data; an additional imagery system such as Pan is used to meet the requirements of
	WSR-88D Radar=ground-based National Weather Service
	Radar=Aerial Radar
	Note: Items in italics are above the minimum spectral resolution requirement, however, the imagery system chosen must also meet the minimum temporal and spatial resolution. Where Multispectral is not used in the table, it is not needed for the requirement.

Below the legend, six columns organize information about each imagery system included in the thesis analysis. This additional information allows a user to see specific details about each imagery system without encumbering the matrix use.

Column 1 has imagery systems listed according to subheadings of archived aerial imagery, satellite imagery, multi-spectral aerial imagery, radar, LiDAR, and low spatial resolution satellite imagery. The imagery systems are randomly ordered under each subheading. The first few imagery systems, temporal resolution, and spatial resolution are shown in Table 4-10.

Column 2 is the temporal resolution for each imagery system. This is how often an imagery system can obtain images of the same geographic area on earth. Values range from a few days to several weeks depending on the capability of the imagery system. Some satellites such as IKONOS can obtain imagery of certain areas at customer request.

The satellite will pass over a geographic region and pinpoint a specific area to image. If tasked, IKONOS can obtain imagery of the same geographic area every two to three days. Satellites such as Landsat-4, 5 Thematic Mapper cover a larger area with lower spatial resolution. Landsat-4, 5 TM each cover the same geographic area every 16 days. The revisit temporal resolution affects two issues, the availability of archived imagery and the availability of on-demand satellite imagery. For instance, archived IKONOS imagery for a geographic location was collected every two to three days. A manager can request the imagery of a location and see if imagery is available. At best, an archive of imagery may be available on the location that was collected by satellite every two to three days. Additionally, if the manager wants to task a satellite to collect imagery for a disaster situation, imagery is only available of the area every two to three days. That is why in emergency situations, managers still need aerial imagery to collect the timely information. As satellite technology progresses, the possibility of getting on-demand imagery from satellite is approaching the temporal resolution for aerial imagery, which is typically every 12 hours.

Column 3 indicates the spatial resolution for each imagery system indicated in meters. When more than one number is listed, there are multiple sensors that obtain imagery and Column 4 discussed next is also directly correlated to the information in Column 3.

Column 4 contains the spectral resolution data for each imagery system. The acronyms for spectral resolution are included in the legend at the top of the key. Quickbird, for instance, obtains 0.61-meter panchromatic imagery and 2.5-meter multi-spectral imagery. A more thorough discussion of spatial resolution and spectral

Table 4-10: Imagery System, Revisit Temporal Resolution, and Spatial Resolution

1. Imagery System	2. Revisit Temporal Resolution	3. Spatial Resolution (m)
Archived Aerial Imagery		
Aerial Imagery, Pan or V	12 hours	Varies depending aircraft altitude
Satellite Imagery		
Quickbird	1-5 days (depends on latitude)	0.61, 2.5
IKONOS	2-3 days	1, 4
OrbView-3,4	< 3 days	1, 4
SPIN-2.	45 days	2, 10
SPOT-1,2,3,4	26 days (1 day with 3 satellites)	10, 20

resolution is in Chapter 2. Table 4-11 has the spectral resolutions, availability, and qualitative cost for the first few imagery systems.

Column 5 contains data on availability of imagery from each imagery system. The availability of the imagery indicates where users can obtain the imagery. Websites are provided. For some of the imagery systems, multiple sources are listed.

Column 6 contains cost information on each imagery system. The various levels assigned to the cost data are minimal, low, medium, and high. Minimal cost (Min) designation is used for imagery that is available to the Department of Defense from agencies such as NIMA and USGS. There may be some minimal fees for obtaining the imagery. Low cost refers to less than $2000 per image, while medium and high cost refers to $2000 to $5000, and greater than $5000 respectively. Issues that will impact cost include the availability of the imagery for a particular geographic area and the requested imagery format. When more than one cost is listed, each cost corresponds to the respective source in Column 5. Imagery listed as minimal cost (Min) may be only accessible through certain contracts or after obtaining the proper license from the agency

indicated. The costs are qualitative and are subject to change. These costs do not include value-added products, such as human resource costs of inputting the imagery into the GeoBase, tailoring the imagery to the specific application and maintaining the imagery in the GeoBase.

Table 4-11: Spectral Resolution, Availability, and Qualitative Cost

4. Spectral Resolution	5. Availability	6. Cost(Qualitative)
Pan, V, NIR, MIR, TIR, M	USGS, Commercial	Min
Pan, M	NIMA	Min
Pan, M	NIMA	Min
Pan, M	NIMA	Min
Pan(panoramic), Pan	NIMA	Min
Pan, M	NIMA	Min

4.3.6 Imagery System Key - Final

The final format of the imagery system key involved several changes. The imagery system key is shown in Appendix D. Several imagery systems were removed from the final imagery system key for simplification. Specifically, MODIS, Spot-4 Vegetation, OrbView-2 SeaWiFS, AVHRR, GOES, METEOSAT, and NWS WSR-88D were removed from the matrix. These imagery systems were associated mainly with weather reporting and environmental changes on a regional or national scale. The spatial resolutions of these imagery systems do not provide as much usefulness to urban and suburban applications as the other imagery systems presented in the key.

The spectral legend of the imagery system key was updated to incorporate wavelengths in the electromagnetic spectrum. The updated spectral legend is shown in Appendix D.

Column 1 of the imagery system key contains category codes, based on low to high spatial resolution, for each imagery system. For aerial platforms, such as Daedalus, the imagery may be category 3 or category 4 depending on the altitude of the aircraft. At a lower altitude, the imagery will have higher spatial resolution making it a category 4. Column 1 of the key can be a quick reference as to the capabilities of each imagery system. Column 1 categories link back to the final imagery decision matrix, Column 5. The manager has the choice of determining the imagery system for his application with the appropriate category code. This is mainly based on spatial resolution; however each imagery system should still be examined to identify additional system details. Table 4-12 details the category code, imagery system, spatial resolution, and spatial resolution for the first few imagery systems.

Columns 2, 3, and 4 contain similar data as outlined in the initial imagery system key. The column numbers are shifted and some formatting changes are made to the display of information.

Column 5, spectral resolution, has a more significant change in formatting. Some imagery systems have multiple bands covering different portions of the mid-infrared, near-infrared, or thermal-infrared segments of the spectrum, such as eight bands from ultraviolet to near-infrared and two thermal-infrared bands for Daedalus. Table 4-13 shows the information for the first few imagery systems presented in Table 4-12.

Column 6 and 7 contain similar data about the availability and cost respectively of each imagery system outlined in the initial key. Column 8 is a general column added at the far right side of the key. Imagery systems are grouped according to researcher-

Table 4-12: Imagery Category, Imagery System, Temporal Resolution, and Spatial Resolution

1. Imagery Category-Range 1 to 4 (low to high)	2. Imagery System	3. Temporal Resolution	4. Spatial Resolution (m)
	Aerial Imagery		
4	Aerial Imagery	On Demand weather permitting	Depends on aircraft altitude
3 or 4 depends on altitude	Daedalus(aerial)	On Demand weather permitting	2.5 at 1000 m AGL
3 or 4 depends on altitude	ATLAS(aerial)	On Demand weather permitting	2.5 at 6000 ft AGL
4	LiDAR	On Demand weather permitting	0.2 horizontal, 0.1 vertical

defined geographic area coverage: precision, local, or regional. These are qualitative measures that indicate how the imagery system can be used. Precision denotes the highest spatial resolution of <2 meters and would allow decisions to be made about a single base facility. Local represents a resolution of 2-15 meters, displaying a broader view of an Air Force base. Regional, with the least spatial resolution capability, >15 meters, would encompass an area as large as a county or state.

Table 4-13: Spectral Resolution, Availability, Cost and General Use

5. Spectral Resolution	6. Availability	7. Cost(Qualitative)	8. General Use
Pan, V, NIR, MIR, TIR, M	USGS, Commercial	Low, High	Precision measurements and analysis
M (8 bands from UV to NIR, and 2 TIR bands)	NIMA possible (http://www.spatial.maine.edu)	Low, High	Precision measurements and analysis
M (6 bands in V and NIR, 2 MIR, 6 TIR)	NASA Stennis Space Center(http://wwwghcc.msfc.nasa.gov)	Med	Precision measurements and analysis
L (Laser)	Commercial	High	Precision measurements and analysis

4.4 Validation

Validation involves two procedures: Geo-Integration Officers evaluating the decision tools, and acquiring imagery that could be used in GeoBase. The validation tests the analysis and procedures proposed by the research. An appropriate breadth and depth of validation is necessary to determine if the analysis and procedures are sound. The end product of this research is the imagery decision matrix, imagery system key, instruction sheet, and procedures for obtaining imagery for Air Force applications. The instruction sheet provides step by step instructions for GIOs to use the matrix and key. The instruction sheet is included in Appendix E.

Three Air Force bases were selected to validate these products and procedures based on the variability of missions, geographic location, Major Command (MAJCOM), background and level of experience of participating validators, and level of GeoBase

implementation at the Air Force base. More specific information on each validation base and validator follows.

Geo-Integration Officers from the United States Air Force Academy, Elmendorf Air Force Base, and Wright-Patterson Air Force Base concurrently validated the imagery decision matrix, imagery system key, and an instruction sheet. The researcher determined if the process of obtaining imagery for the three sample Air Force bases was plausible and practical. The validation determines the usefulness of the matrix and the researcher records suggestions, benefits and difficulties the GIOs had from using the matrix, key, and instruction sheet.

4.4.1 United States Air Force Academy, Colorado

Comments were positive from the USAFA Chief of Geospatial Information and Services Center. The GIO found the matrix to be very useful and a tool that presents a variety of new options (Portillo, 2003). He indicated that he would use the matrix for future decisions regarding imagery implementation. Although some GIOs are not using the latest satellite imagery, he currently is using IKONOS satellite imagery and aerial imagery.

The initial imagery decision matrix, initial imagery system key, and instruction sheet were sent to GIOs for validation. The initial imagery decision matrix included a column for recommended imagery systems rather than a category of systems in the final imagery decision matrix. The GIO was interested in the criteria used to determine the recommended imagery. The researcher clarified the three selection criteria: fulfillment of resolution requirements, minimizing inventory, and low cost priority. After consideration, the recommended imagery was removed from the final matrix. This

column of information was not presented because a more thorough understanding of the nuances of each imagery system is required to make this determination and each manager can best decide the particular imagery system for a given problem. By presenting the systems by category code that meet the requirements, the manager then can select the one that best meets their specific requirements.

The GIO commented that an experienced GIS specialist most easily uses the matrix. Another suggestion by the GIO was to merge multiple imagery sources to create a product. The GIO used this method in the past with SPOT 5 imagery and Quickbird imagery. The SPOT 5 imagery was used for the majority of the coverage, with Quickbird imagery merged at specific areas that require higher spatial resolution. This method is recommended in the future research section of this document as an alternative imagery product for applications in GeoBase. Also, the GIO was aware of imagery at minimal cost from NIMA and how to access it. NIMA-archived imagery of the Air Force Academy is noted later in this section.

4.4.2 Elmendorf Air Force Base, Alaska

The Elmendorf AFB GIO found the matrix and key to be easy to follow with the supplemental instruction sheet. The temporal resolution indicated in the matrix was appropriate based on his experience. Imagery recommendations were evaluated as good. The GIO plans on keeping the matrix in a “tool box” as a useful reference for future imagery application decisions (Brown, 2003).

One drawback to the matrix, according to the GIO, was that three-spectral band color imagery was not clearly indicated. Based on this feedback, first imagery system,

aerial imagery, was updated in the final matrix to indicate that panchromatic and visible color imagery is included.

The GIO expressed that he had difficulty obtaining imagery from NIMA in the past. He was in the process of seeking $10,000 to acquire imagery needed for the base. The researcher obtained imagery from NIMA through the Commercial Satellite Imagery Library and sent the imagery to the Elmendorf GIO.

The GIO had difficulty using one of the websites suggested for obtaining NASA imagery. The researcher provided the GIO with a more direct website. http://edcdaac.usgs.gov/aster/aster_pricing.html. NASA imagery is archived by the USGS EROS Data center and is available by request. This process is further discussed in Section 4.4.4.

4.4.3 Wright-Patterson Air Force Base, Ohio

A team member from the Wright-Patterson GIO determined that the matrix was "an interesting compilation of the various technologies being used for satellite imagery" (Castaneda, 2003). Wright-Patterson is still in the developmental stage of inputting their data and imagery into a GeoBase. Satellite imagery will be incorporated later for specific applications once the initial GeoBase is operable. The GIO plans on using the matrix for implementing satellite imagery into GeoBase.

The GIO suggested applying the matrix to GeoReach activities where quick-turn imagery is necessary. Careful consideration was given to this issue; however, a separate analysis of the appropriate imagery systems is necessary for unique wartime situations. This will be discussed in the future research section of this thesis, Section 5.4.

The GIO recommended that on-demand aerial imagery be included in the matrix as a benchmark for cost and applications. He noted that, in the past, Wright-Patterson AFB has mainly used on-demand aerial imagery for its GIS. If the cost and applications of on-demand aerial imagery were integrated into the matrix, this could be used as a comparison to archived satellite imagery.

Satellite imagery is lower in cost. As satellite imagery progresses in spatial, spectral, and temporal resolution; satellite imagery may replace the need for aerial on-demand imagery. The on-demand aerial imagery is incorporated into the imagery system key, under Daedalus, a commercial aerial imagery system. Each decision-maker will have to determine the cost for obtaining on-demand aerial imagery for their needs and geographic region. Providing a specific dollar value for obtaining on-demand aerial imagery could be misleading due to the variability of each situation. Therefore, specific dollar values are not included in the imagery system key.

4.4.4 Imagery Procurement

Validation is used to determine whether the processes suggested by the research are plausible and practical. The process of procuring imagery was an important undertaking of this research. Information was obtained indicating that a wide range of imagery is available to Department of Defense organizations at minimal cost through NIMA (Commercial Imagery Copyright & License Interim Guidance, 2002). Another major source of imagery is the USGS. The process of obtaining imagery from USGS was investigated, however NIMA was chosen as the primary imagery source for this research because of its extensive commercial inventory. Imagery for the three validation bases was available from NIMA. Imagery was requested for Elmendorf Air Force base.

A document titled, Commercial Imagery Copyright and License Interim Guidance, details the Unclassified commercial imagery available through NIMA (2002). According to this document, as stated in Department of Defense (DoD) Directive (DoDD) 5105.60, NIMA will "serve as the sole DoD action agency for all purchases of commercial and foreign government-owned imagery-related remote sensing data by the DoD Components (and) serve as the primary action agency for such purchases by any other Federal Department or Agency, on request" (2002). NIMA will provide imagery at minimal cost that it has acquired to any United States government entity with priority support given to the Intelligence community and State Department customers. The documentation is set to provide imagery to DoD Agencies; however the process to distribute the imagery does not work well.

The process of obtaining imagery for the three validation Air Force bases proved more difficult than anticipated. Imagery is easily accessible to government agencies that are part of the intelligence community, such as the National Air Intelligence Center (NAIC), and the Central Intelligence Agency (CIA). Contact was made with eight personnel at NIMA including the imagery program directors in Virginia and St. Louis offices, and no one provided a solution. Without access to an Internet connected Secret or Top Secret computer system, the NIMA Commercial Satellite Imagery Library (CSIL) is unavailable to Department of Defense organizations. A user also would need a license granted by NIMA to use the imagery.

Many lessons were learned while attempting to obtain Unclassified commercial imagery from NIMA. Imagery is available at minimal cost to U.S. government agencies via Secret or Top Secret networked computers. With the help of an intelligence agency

employee with Secret or Top Secret Internet access, this imagery can be procured. Once an organization searches the CSIL and submits an order, a compact disc containing the imagery is sent by mail. The imagery is purchased by NIMA as needed from commercial sources and made available to government agencies. Special requests can be made for imagery if it is not available in the CSIL, but the requestor may incur an additional cost. The Intelligence community has priority when making imagery requests. Ordering imagery via Unclassified Internet was a NIMA initiative that was planned and then delayed as a consequence of September 11, 2001.

Geographic coordinates are required when searching for imagery in NIMA's database. The geographic coordinates for the three bases were found on several websites using an online search engine. Coordinates were input to the Commercial Satellite Imagery Library (CSIL) on a Top Secret computer system. A user can either type a center point for the geographic location or input the upper left and lower right corner coordinates, creating the rectangular area of coverage needed. The search can be narrowed using several parameters including dates of acquisition, satellite track, country imaged, maximum cloud cover percentage, and specific imagery systems.

Imagery was located for each of the three validation bases using center search point coordinates. Through the CSIL, Landsat-5 TM10, Landsat-7 ETM+, and IKONOS-1, 2 multi-spectral, provided coverage for Wright-Patterson AFB. Landsat-7 ETM+, Landsat-5 TM, RADARSAT-1, and Landsat-5 imaged the Air Force Academy. SPOT-1 panchromatic, RADARSAT-1, and IKONOS-1 panchromatic and multi-spectral covered Elmendorf AFB. Imagery for Elmendorf AFB was downloaded from NIMA.

Figure 4-2 is an IKONOS 1-meter spatial resolution, black and white panchromatic of Elmendorf AFB collected in year 2000. Commercial and residential areas are visible in the image as well as main and side roadways. With a 17” computer monitor, cars can be distinguished traveling on the roadways. This data from this image can be used for land-use planning, distance and area measurements, and pre-emergency imagery to name a few.

Figure 4-2: IKONOS 1-Meter Black and White Panchromatic (NIMA, 2003)

Figure 4-3 is an IKONOS 4-meter near-infrared band from a multi-spectral collection in 2000. The image shows the golf course area of Elmendorf AFB. The long narrow brighter strips are the golf course fairways. Because healthy vegetation reflects near-

infrared energy more than stressed vegetation, the fairways of the golf course appear brighter than the surrounding vegetation. The IKONOS imagery for Elmendorf AFB was provided to the Elmendorf GIO. He plans to use the imagery for base planning and environmental analysis.

Figure 4-4: IKONOS 4-Meter Near-Infrared Band from Multi-Spectral Imagery (NIMA, 2003)

Issues of concern when obtaining imagery for each validation Air Force base were cloud cover, availability of the imagery, and format compatibility of the imagery with GIS software programs. Cloud cover is usually not a problem with commercial imagery provided by NIMA because the imagery is produced to sell in an open market. This commercially accepted imagery is provided to government agencies at minimal cost. The

availability of imagery has not been a problem with imagery from the past two or three years available from NIMA. Geo-referenced data is the standard provided by NIMA on compact disc or through an Internet download (Bignell, 2003). This geo-referenced data is provided in a format that is compatible with Geographic Information Systems (GIS) software such as ESRI ArcView 8.1. ArcView 8.1 is frequently the GIS software used by Air Force bases.

The USGS is also a source of imagery. ASTER imagery is available at minimal cost to DoD by Internet request. The website is http://edc.usgs.gov/. According to personnel at the USGS, Earth Resources Observation Systems (EROS) Data Center, a request form for imagery must be filled out. Then an email is sent to the requester to notify whether or not the imagery is approved for release. The process may take a few weeks.

4.4.5 Imagery Decision Flow Chart

A flow chart was envisioned as an alternative to the matrix, key, and supplemental instruction sheet. A preliminary flow chart will be included in Chapter 5 as a recommendation for future development. The flowchart could be used as a foundation for developing a software program. The ideas for the software program will be discussed further in Chapter 5 in the future recommendations section.

V. Conclusions

5.0 Introduction

An imagery decision matrix, imagery system key, and instruction sheet were developed from research of civilian and government applications of remote sensing imagery. These products were validated with GeoBase personnel at three diverse Air Force bases. The process of obtaining imagery from NIMA was detailed, and these products were made available to the GIOs from the three validation bases.

5.1 Results

The imagery decision matrix, imagery system key, and instruction sheet provide a useful guidance tool to GeoBase personnel. The spreadsheet format of the matrix and key combined a decision tool with satellite imagery information into one resource. The instruction sheet provides easy to follow steps on using the matrix and key.

The matrix addressed many Air Force mission requirements including infrastructure, natural resource management, and command and control. A wide range of imagery applications was presented in the matrix. The applications are relevant to peacetime operations at Air Force bases.

GeoBase personnel at three Air Force bases validated the matrix, key, and instruction sheet. They made recommendations for improvement and provided feedback about the usefulness of these tools. Their recommendations and comments were incorporated into the final version of the matrix, key, and instruction sheet. The result of their participation in the research is a more precise tool for use by GeoBase personnel.

Rather than provide the imagery for a specific application to the validation bases, the imagery available at NIMA was offered to the three validation base GIOs. The Air Force Academy GIO had previously acquired imagery for his base requirements from NIMA and commercial sources. Therefore he did not need the imagery that was identified at NIMA. The Wright-Patterson GIO decided it would be best to determine exactly what imagery the base could use before proceeding with a request of imagery. Wright-Patterson AFB is in the early phases of implementing GeoBase, and the GIO wanted to make a full evaluation of their needs before requesting imagery from NIMA. The Elmendorf GIO requested the IKONOS imagery to use for environmental and infrastructure planning at the base. Obtaining the imagery was more difficult than expected. Due to time constraints the imagery was made available to the Elmendorf GIO, but there was no time to receive feedback from the GIO concerning implementation of the imagery for environmental and infrastructure planning.

Imagery of three validation bases was successfully accessed from a classified government computer system with the help of an employee from the National Air and Intelligence Center (NAIC), Wright-Patterson Air Force Base.

5.2 Summary

The U.S. Air Force is in the process of implementing GeoBase, a geographic information system (GIS), throughout its worldwide installations. The Air Force has GIS needs that can be augmented by readily available imagery. An extensive survey and compilation of imagery applications provides decision-makers focused with focused information. Incorporating various imagery types will significantly increase GeoBase usefulness for a range of mission requirements. Potential Air Force uses of imagery

include identifying heat loss, environmental monitoring, command decision-making, and emergency response.

Findings from current literature, results from an Air Force Geo-Integration Office (AF/GIO) survey, and insights from a Geospatial Technologies Symposium, were used to develop a comprehensive imagery applications list that satisfies Air Force mission requirements. An imagery decision matrix was developed that allows users to select an application and identify the most ideal imagery for accomplishing the task. Potential uses of various satellite and aerial imagery capitalize on the technological innovations over the past few years, a tremendous opportunity for GeoBase enhancement. A supplemental imagery system key provides further details of each imagery type. Geo-Integration personnel at three Air Force bases evaluated the matrix. Their feedback strengthened the decision matrix tool and provided a valuable exchange of ideas regarding implementation of multiple imagery types in GeoBase. The products of this thesis effort will help decision makers enhance the capabilities of their GeoBase, saving time, increasing efficiency, and creating continuity.

An increased awareness of the possibilities of GIS, when enriched by imagery, and the efficiency afforded by the matrix, greatly reduces time required by GeoBase personnel to identify and implement the optimum imagery. The gap is bridged between a simple GIS and a multi-faceted GeoBase with guidance presented in the matrix. GeoBase personnel have the opportunity to exploit the capabilities afforded by commercial satellite imagery. An enhanced GIS can include multiple types of imagery. A simple GIS may have only one type of image such as a black and white panchromatic.

By incorporating multiple types of imagery, decision makers have a powerful analysis tool to make more informed decisions.

This thesis effort tapped imagery from NIMA, which is available through its online Commercial Satellite Imagery Library. Presently, this library is only available through classified internet access. The NIMA imagery can be obtained for a minimal cost, with the assistance of intelligence personnel at the base level.

These research results have the potential to dramatically increase the capability of GeoBase. The matrix serves as a practical guide for decision-makers to determine the most appropriate imagery for a given application. All three validators of the matrix, key, and instruction sheet plan to use these tools when making imagery decisions for the Air Force.

5.3 Limitations

Some limitations were identified with regard to the usability of the matrix, key, and instruction sheet; the imagery procurement process; and the applications focus. One of the challenges of making the matrix, key, and instruction sheet is how to determine an appropriate level of detail. During the process of constructing these products, the researcher made the assumption that the intended users of the matrix, key, and instruction sheet would be GIOs. Experienced GIS personnel are the preferred users of the imagery decision matrix, imagery system key, and instruction sheet. A substantial working knowledge of GIS and remote sensing imagery is recommended for successful understanding and implementation of the matrix.

Most of the applications presented in the matrix relate to Civil Engineering operations. Applications detailed in current literature emphasize environmental and

infrastructure management projects. These types of applications are typically the responsibility of the Air Force Civil Engineer. As more research on diverse applications becomes available, the matrix can be updated to incorporate the applications of other career fields. With remote sensing technology advances and continued innovations in the practical use of imagery, the GeoBase applications scope will broaden.

When base-level GIOs attempt to obtain imagery, they may encounter some limitations. These issues are best illustrated by an example: A GIO may require 1-meter or better spatial resolution satellite imagery collected in 2002. The GIO intends to use this imagery for distance and area measurements and elevations of all base facilities. Several new buildings have been constructed since 2000. When the GIO makes a request from NIMA, the most current imagery available that fulfills the 1-meter requirement was collected by IKONOS satellite in 1999. Although the spatial resolution meets the GIO's requirements, the imagery is not current enough to reflect the newer base facilities. The imagery would also need to be cloud-free and properly formatted for GeoBase compatibility. In this case, the GIO has two options. Make a special request to NIMA for more current imagery to fulfill the requirement or obtain the imagery through another source. Special requests to NIMA may require funding from the GIO's Air Force base; however if several organizations request the imagery, the cost may be split among them.

5.4 Future Research

Many opportunities remain to be studied as they apply to GeoBase. Future research related to this thesis effort should focus on several issues: improving usability of the matrix, key, and instruction sheet; implementation of the imagery into GeoBase; widening the applications focus to encompass all Air Force squadrons on a typical base;

exploring additional imagery types, merging imagery, acquiring imagery, and wartime imagery applications.

Further development into the usability of the matrix, key, and instruction sheet would enable wider use of the decision making tool. One of the limitations of the matrix, key, and instruction sheet is that a high-level of GIS experience is needed to fully understand and make decisions based on the information provided. By reading the thesis, most users without prior GIS experience should gain enough background knowledge to use the matrix, key, and instruction sheet effectively. As more individuals incorporate the decision tool into daily operations, adjustments should be made so people with minimal GIS competence can use it. Another idea is to develop a separate software program that assimilates all of the information from the key, matrix, instruction sheet, and provides additional information when requested by the user. An option considered for presenting the information was the Microsoft Visual Basic software application.

Visual Basic could be used to build an interactive Microsoft Windows imagery decision software program. Visual Basic uses a Microsoft Windows graphical user interface. The beginning stage of this software program is illustrated in an imagery decision flowchart, included in Appendix F of this document.

To use the flowchart, start at the upper left side at spatial resolution. Determine the spatial resolution requirement for a specific application and either progress to the spectral resolution or proceed to the next page for higher spatial resolution. If >20-meter spatial resolution fulfills the requirement, next determine the spectral resolution requirements. The first three spectral resolutions are organized from left to right in increasing spectral resolution capability. If panchromatic imagery (Pan) fulfills the

spectral resolution requirement, Landsat-7 is the recommended imagery system. If not, the subsequent spectral resolutions listed are multi-spectral without thermal-infrared capability (MS no TIR), multi-spectral with thermal-infrared capability (MS w/ TIR), Elevations, and Cloud covered. Each of these indicates a recommended imagery system that fulfills the requirement. Multi-spectral and thermal-infrared applications are detailed in Chapter 2 and in the final imagery decision matrix. LiDAR is typically used if the application is to obtain elevations and area measurements for natural resources. Radar is typically used for geographic areas that have constant cloud cover. Several external considerations may be built into the program, including an imagery procurement timeline, imagery updating frequency (temporal resolution), and imagery acquisition budget.

This flowchart and subsequent software program is an idea that will need further development. With software programming, the decision tool could link to imagery examples for each imagery system. The software program could have an Internet link to an Unclassified NIMA commercial imagery website if it becomes available. Internet links could also connect to additional sources of imagery such as USGS. The flowchart assumes that each decision is independent of the others. A GIS professional would likely make an imagery decision accounting for all variables at the same time. Spatial, spectral, and temporal resolution; timeline; frequency; and budget are dependent variables that affect the final decision of which imagery source to choose.

Implementation of the imagery into GeoBase will allow researchers to determine the extent of capability gained by use of additional imagery types. Research is needed that addresses appropriate amount and type of information made available to users to

effectively and efficiently complete their work. Too much data in the GeoBase may make maintaining the GeoBase difficult. While there are many capabilities afforded by imagery enhancement of GeoBase, GIOs have to be selective when acquiring and maintaining imagery for their requirements.

Wider validation of the decision tool presented in this research is needed. The validation should encompass horizontal and vertical integration on each Air Force base. Horizontal integration with Intelligence, Security Forces, and Communications Squadrons, to name a few, will generate mission-specific uses of the matrix. Air Force base GIOs should partner with intelligence squadron personnel at base level to obtain imagery from NIMA. Improved continuity in terms of information sharing will be possible with wider use of a common imagery decision tool.

Vertical integration of the matrix will provide personnel with a tool, which will facilitate communication regarding GeoBase imagery requirements and solutions. By using a common decision analysis tool, improvements and updates can be made that will benefit users of GeoBase.

Exploration of imagery merging, imagery acquisition, and additional types of imagery is needed. Imagery merging is taking more than one imagery source and combining them to make a composite image. This method is used to reduce the cost and time of acquiring imagery at higher resolution for an entire geographic area. A higher resolution may only be required for small parts of a geographic area of interest. Often, archived imagery of a large geographic area is merged with more current higher-resolution imagery. A merged imagery product reduces the time and cost associated with

replacing all of the imagery of an entire geographic area with a costlier, higher-resolution product.

Exploration of additional imagery sources and their implementation into GeoBase is needed. There are many sources of imagery that may enable GeoBase personnel to inexpensively enhance their GIS. Additional emphasis on acquiring imagery from new commercial sources as they become available will provide the GeoBase with the most current and capable imagery.

New computer systems coming on line at the base level such as Theater Battle Management Core System (TBMCS) have SIPRnet Secret internet connection capability. Squadron Commanders can obtain access to NIMA imagery at the Commercial Satellite Imagery Library (CSIL) through SIPRnet-connected computer systems. This may be the best way to obtain Unclassified imagery for GeoBase use until the CSIL is made available on Unclassified Internet-connected computers. However, the most compelling reason that imagery should be made available through Unclassified access is that Unclassified imagery accounts for a large percentage of the inventory. One source at NIMA noted that 900,000 satellite images were available from Space Imaging, Inc. through NIMA's Commercial Satellite Imagery Library (CSIL). Only a few satellite images may be necessary to provide full coverage of an Air Force base.

The GeoBase concept, when used in a deployment, is known as GeoReach. GeoReach database requirements are similar to those for GeoBase, with additional contingency requirements. Personnel working in a deployed location should have access to real-time classified imagery. The real-time classified imagery may provide additional capabilities to deployed GIOs. This research may be applied to GeoReach with

contingency requirements taken into account, such as the necessity for real-time classified imagery, and the need to collect aerial imagery at a higher altitude. Real-time classified imagery may be required in situations where the features in the geographic environment are changing rapidly. It may be possible to track the enemy positions through real-time classified imagery to gain advantages over the enemy. Aircraft are at risk of attack when flying within range of surface-to-air (SAM) missiles and anti-aircraft artillery (AAA) in a war zone. For this reason, war zone remote sensing aerial platforms need to operate at a much higher altitude than for peacetime collection.

Imagery applications that would greatly improve the capability of GeoBase include chemical plume detection and asbestos identification, but these require further exploration into new types of imagery. Chemical plume detection and mapping is an area of interest in cases of environmental monitoring and disaster management. The ability to track the plume of chemicals would enable commanders to make more informed decisions regarding safety and cleanup. Asbestos identification through the use of advanced imagery would enable airmen to determine those facilities that have specific requirements regarding asbestos. Once the facilities that have asbestos are identified, appropriate action can be taken to encapsulate the asbestos or remove it properly. Hyper-spectral imagery may be the next step in fulfilling these challenging requirements.

Hyper-spectral imagery expands upon the capabilities provided by multi-spectral imagery. Hyper-spectral imagery is made up of hundreds of spectral bands while multi-spectral typically has less than a dozen. The higher number of spectral bands allows the electromagnetic spectrum to be split up into smaller sections, thereby creating greater precision when distinguishing features in an image. Hyper-spectral imagery was not

included in this thesis because of time constraints. The decision was made to focus on panchromatic and multi-spectral imagery; and exclude hyper-spectral imagery.

GeoBase can greatly benefit from the multi-spectral, LiDAR, and radar imagery systems. By focusing on these imagery systems, a greater degree of depth can be presented without the need to introduce the complexity of hyper-spectral imagery at this early stage of GeoBase implementation. Additional research is needed on hyper-spectral imagery to determine possible applications. Hyper-spectral imagery may provide the capability to detect chemical plumes (Frohn, 2002).

Appendix A: Initial Imagery Decision Matrix

This appendix contains the initial imagery decision matrix. The matrix has 7 columns of data to help decision-makers determine the appropriate imagery for a particular application. A more detailed discussion of each column is in Chapter 4.

Jensen's textbook, Jensen and Cowen's journal article, and a NIMA document were used as references for the imagery decision matrix and imagery system key. They are as follows:

Jensen, John R. *Remote Sensing of the Environment An Earth Resource Perspective*. Upper Saddle River, New Jersey: Prentice-Hall Inc., 2000.

Jensen, John R. and Dave C. Cowen, "Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*," *Photogrammetric Engineering & Remote Sensing,* 65: 611-622 (May 1999).

"Status of Selected Current & Future Commercial Remote Sensing Satellites." National Geospatial Intelligence School, NIMA. Handout from a seminar. 24 June 2002.

Table 1.						
Imagery Decision Matrix-Initial		Minimum Resolution Requirements				
1. Applications	**2. Attributes**	**3. Temporal**	**4. Spatial**	**5. Spectral**	**6. Imagery System**	**7. Notes**
	Land Use/Land Cover					
	L1-USGS Level I	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	
					Landsat 4,5,7	
					JERS-1	
					RADARSAT	
					ERS-1,2.	
	L2-USGS Level II	5-10 years	5-20 m	V-NIR-MIR-Radar-*M-*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	
					Landsat 7-Pan only	
					Radar	
	L3-USGS Level III	3-5 years	1-5 m	Pan-V-NIR-MIR-*M-LiDAR*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	
	L4-USGS Level IV	1-3 years	0.25-1 m	Pan-*M-LiDAR*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	

	Building and Property Infrastructure					
Distance and area measurements	B1-building perimeter, area, height and cadastral information (property lines)	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Aerial Photography	
Digging Permits						
Community planning						
Building footprints						
Spot heights						
Facility elevations						
3-dimensional rendering						
Facility management						
	Transportation Infrastructure					
	T1-general road centerline	1-5 years	1-30 m	Pan-V-NIR-*M*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 1,2,3,4,5	
					IRS-P5	
					Landsat 7 ETM	
					JERS-1	
Transportation management	T2-precise road width	1-2 years	0.25-0.5 m	Pan-V	Aerial Photography	
Traffic studies	T3-traffic count studies (cars, airplanes, etc.)	5-10 minutes	0.25-0.5 m	Pan-V	Aerial Photography	
	T4-parking studies	10-60 minutes	0.25-0.5 m	Pan-V	Aerial Photography	
	Utility Infrastructure					
Powerline detection	U1-general utility line mapping and routing	1-5 years	1-30 m	Pan-V-NIR-*M*-*LiDAR*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	

					SPIN 2.	
					SPOT 1,2,3,4,5	
					IRS-P5	
					Landsat 7 ETM	
					JERS-1	
	U2-precise utility line width, right-of-way	1-2 years	0.25-0.6 m	Pan-V-*LiDAR*	Aerial Photography	
	U3-location of poles, manholes, substations	1-2 years	0.25-0.6 m	Pan-*LiDAR*	Aerial Photography	
	Digital Elevation Model (DEM) Creation					
Earthwork	D1-large scale DEM	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Aerial Photography	
Highway alignment						
Coastal structure design						
Soil erosion modeling						
Flood prevention and planning/buffer						
Drainage						
Hydrology modeling						
Contour generation	D2-large scale slope map	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Aerial Photography	
	Socioeconomic Characteristics					
Population estimation	S1-local population estimation	5-7 years	0.25-5 m	Pan-V-NIR-*Radar-LiDAR*	Aerial Photography	
Urban sprawl					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	

	S2-regional/national population estimation	5-15 years	5-20 m	Pan-V-NIR-*Radar-LiDAR*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	
					Landsat 7 ETM	
Quality of life analysis	S3-qualtiy of life indicators	5-10 years	0.25-30 m	Pan-V-NIR-*Radar-LiDAR*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	
					Landsat 7 ETM	
					JERS-1	
	Energy Demand and Conservation					
	E1-energy demand and production potential	1-5 years	0.25-1 m	Pan-V-NIR	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
Building heat loss	E2-building insulation surveys	1-5 years	1-5 m	TIR	Aerial Photography	
Pipe heat loss-(Steam, hot water)						
	Meteorological Data					
	M1-weather prediction	3-25 minutes	1-8 km	V-NIR-TIR	GOES	
					METEOSAT	
	M2-current temperature	3-25 minutes	1-8 km	TIR	GOES	
	M3-clean air and precipitation mode	6-10 minutes	1 km	WSR-88D Radar	NWS WSR-88D	
	M4-severe weather mode	5 minutes	1 km	WSR-88D Radar	NWS WSR-88D	

	M5-monitoring urban heat island effect	12-24 hours	5-30 m	TIR	Aerial Photography	
	Critical Environmental Area Assessment					
Land/water boundary ID	C1-stable sensitive environme	1-2 years	1-10 m	*Pan*-V-NIR-MIR-*Radar*-*LiDAR*	Aerial Photography	
Health and abundance of	stable sensitive=wetlands, endangered species habitats, parks, treatment plants, urbanized watersheds potable water runoff (Jensen and Cowen, 1999:620).				Quickbird	
Suspended sediment/organic					IKONOS	
Clear-cut forest ID					OrbView 3/4	
					SPIN 2.	
Habitat modeling (Bird strike hazard)						
Aquifer/well water resource					SPOT 5	
Forest management					IRS-P5	
Wildlife management						
Rangeland management						
Wetland/watershed management						
Agricultural management						
Urban vegetation management						
Environmental assessment (EIS, EA)						

Environmental hazards	C2-dynamic sensitive environments, where dynamic sensitive=critical areas that could chage rapidly (Jensen and Cowen, 1999:620)	1-6 months	0.25-2 m	*Pan*-V-NIR-MIR-TIR-*M*	Aerial Photography	Panchromatic only for IKONOS and
Thermal pollution					Quickbird	Multispectral only with aerial to meet spatial res. Req.
Environmental assessment (EIS, EA)					IKONOS	TIR, Other missions may benefit from Pan, V, NIR, MIR alone
					OrbView 3/4	
	DE1-pre-emergency imagery	1-5 years	1-5 m	Pan-V-NIR--*M*-*LiDAR*	Aerial Photography	
					Quickbird	
					IKONOS	
					OrbView 3/4	
					SPIN 2.	
					SPOT 5	
					IRS-P5	
Fire Response GPS/GIS Tracking System	DE2-post-emergency imagery	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M*-*LiDAR*	Aerial Photography	
Fire Management					Quickbird	
Disaster response					IKONOS	
Environmental cleanup						
Aircraft accident						
Elevation data					OrbView 3/4	
Cordon tool					Radar	
Disaster response	DE3-damaged housing stock	1-2 days	0.25-1 m	Pan-V-NIR--*M*-*LiDAR*	Aerial Photography	
Cordon tool					Quickbird	
					IKONOS	
					OrbView 3/4	
Disaster response	DE4-damaged transportation	1-2 days	0.25-1 m	Pan-V-NIR--*M*-*LiDAR*	Aerial Photography	
Cordon tool					Quickbird	
					IKONOS	
					OrbView 3/4	

Disaster response	DE5-damaged utilities, services	1-2 days	0.25-1 m	Pan-V-NIR-*M-LiDAR*	Aerial Photography	
Cordon tool					Quickbird	
					IKONOS	
	Future Needs					
Noise contour mapping						
Asbestos identification						

Appendix B: Final Imagery Decision Matrix

This appendix contains the final imagery decision matrix. The matrix has five columns of data to help decision-makers determine the appropriate imagery for a particular application. A more detailed discussion of each column is in Chapter 4.

Jensen's textbook, Jensen and Cowen's journal article, and a NIMA document were used as references for the imagery decision matrix and imagery system key. They are as follows:

Jensen, John R. *Remote Sensing of the Environment An Earth Resource Perspective*. Upper Saddle River, New Jersey: Prentice-Hall Inc., 2000.

Jensen, John R. and Dave C. Cowen, "Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*," *Photogrammetric Engineering & Remote Sensing,* 65: 611-622 (May 1999).

"Status of Selected Current & Future Commercial Remote Sensing Satellites." National Geospatial Intelligence School, NIMA. Handout from a seminar. 24 June 2002.

Table 1.				
Imagery Decision Matrix	**Minimum Resolution Requirements**			**5. Imagery**
1. Applications	**2. Temporal**	**3. Spatial**	**4. Spectral**	**Systems**
Urban or built-up land identification	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
Residential areas delineated	5-10 years	5-20 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 2
Single family residential identified	3-5 years	1-5 m	Pan-V-NIR-MIR-*M-LiDAR*	Category 3
Distance and area measurements, building footprints	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Facility elevations	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Community planning	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Population estimation	5-7 years	0.25-5 m	Pan-V-NIR-*Radar-LiDAR*	Category 4
Urban sprawl	5-7 years	0.25-5 m	Pan-V-NIR-*Radar-LiDAR*	Category 4
Building heat loss identified	1-5 years	1-5 m	TIR	Category 3
Commercial and services identified	5-10 years	5-20 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 2
Commercial delineated	3-5 years	1-5 m	Pan-V-NIR-MIR-*M-LiDAR*	Category 3
Coastal structure design	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Drainage patterns obtained	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Facility management	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Asbestos identification (Future application)	Single Collection	<1 m	Hyperspectral	Category 4
Noise contour mapping (Future application)	1-2 years	1-5 m	LiDAR	Category 3
Pipe heat loss identified-(Steam, hot water)	1-5 years	1-5 m	TIR	Category 3
Transportation, Airfield, Communications, and Utilities identified	5-10 years	5-20 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 2
Transportation management (repairs)	1-2 years	0.25-0.5 m	Pan-V	Category 4
Traffic studies (parking; conjested areas)	5-10 minutes	0.25-0.5 m	Pan-V	Category 4
Digging Permits (site information)	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Highway alignment planning	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Urban vegetation management	1-2 years	1-10 m	*Pan*-V-NIR-MIR-*Radar-LiDAR*	Category 2
Environmental assessment (EIS, EA) site planning, stable environment	1-2 years	1-10 m	*Pan*-V-NIR-MIR-*Radar-LiDAR*	Category 2
Quality of life analysis (for a community)	5-10 years	0.25-30 m	Pan-V-NIR-*Radar-LiDAR*	Category 2
Agriculture identified	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
Agricultural management (Health and abundance of vegetation determined)	1-2 years	1-10 m	*Pan*-V-NIR-MIR-*Radar-LiDAR*	Category 2
Aquifer/well water resource management	1-2 years	1-10 m	*Pan*-V-NIR-MIR-*Radar-LiDAR*	Category 2
Rangeland identified	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
Rangeland management	1-2 years	1-10 m	*Pan*-V-NIR-MIR-*Radar-LiDAR*	Category 2

Forest Land identification	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
Forest management(deciduous, evergreen, or mixed identification)	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Clear-cut forest identification	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Water identification	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
Land/water boundary identification	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Soil erosion modeling	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Flood prevention and planning tool	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Hydrology modeling	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Suspended sediment/organic matter identification	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Pollution identification	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Thermal pollution of waterways	1-6 months	0.25-2 m	*Pan-* V-NIR-MIR-TIR-*M*	Category 3
Wetland identification	5-10 years	20-100 m	V-NIR-MIR-Radar-*M-LiDAR*	Category 1
Multiple Categories: These applications may fit multiple categories above				
Habitat modeling (Bird strike hazard)	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Wildlife management	1-2 years	1-10 m	*Pan* -V-NIR-MIR-*Radar-LiDAR*	Category 2
Mapping of airborne chemical plumes	<30 minutes	0.25-1 m	Hyperspectral	Category 4
Emergency Actions				
Pre-emergency imagery	1-5 years	1-5 m	Pan-V-NIR--*M-LiDAR*	Category 3
Environmental hazards Identification	1-6 months	0.25-2 m	*Pan-* V-NIR-MIR-TIR-*M*	Category 3
Fire Response GPS/GIS Tracking System	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
Fire Management	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
Aircraft accident	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
Disaster response	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
Cordon tool	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
Environmental cleanup	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
Elevation data of emergency areas	12 hours-2 days	0.25-2 m	Pan-V-NIR-Radar--*M-LiDAR*	Category 3
General Topographic Data				
Contour generation	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Spot heights	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
3-dimensional rendering	1-5 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4
Earthwork	5-10 years	0.25-0.5 m	Pan-V-*LiDAR*	Category 4

Appendix C: Initial Imagery System Key

This appendix contains the initial imagery system key. The matrix has six columns of data to help decision-makers with detailed capabilities about each imagery system outlined in the thesis. A more detailed discussion of each column is in Chapter 4.

Jensen's textbook, Jensen and Cowen's journal article, and a NIMA document were used as references for the imagery decision matrix and imagery system key. They are as follows:

Jensen, John R. *Remote Sensing of the Environment An Earth Resource Perspective*. Upper Saddle River, New Jersey: Prentice-Hall Inc., 2000.

Jensen, John R. and Dave C. Cowen, "Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*," *Photogrammetric Engineering & Remote Sensing,* 65: 611-622 (May 1999).

"Status of Selected Current & Future Commercial Remote Sensing Satellites." National Geospatial Intelligence School, NIMA. Handout from a seminar. 24 June 2002.

Table 2.

Imagery System Key-Initial	Pan=Black and white panchromatic(0.5-0.7µm) V=visible color(0.4-0.7µm)
SPECTRAL LEGEND:	NIR=Near-infrared including black and white infrared, color infrared (0.7-1.1µm)
	MIR=Mid-infrared including black and white infrared, color infrared(1.5-2.5µm)
	TIR=Thermal infrared(3-12µm)
	M=Multi-spectral (Includes V, NIR,MIR, and depending on sensor; TIR)
	L=Light Detection and Ranging (LiDAR)
	Note: LiDAR is used mainly for elevation data; an additional imagery system such as Pan is used to meet the requirements of the mission
	WSR-88D Radar=ground-based National Weather Service Weather Surveillance Radar
	Radar=Aerial Radar
	Note: Items in italics are above the minimum spectral resolution requirement, however, the imagery system chosen must also meet the minimum temporal and spatial resolution. Where Multispectral is not used in the table, it is not needed for the requirement.

1. Imagery System	**2. Temporal Resolution**	**3. Spatial Resolution (m)**	**4. Spectral Resolution**	**5. Availability**	**6. Cost(Qualitative)**
Archived Aerial Imagery					
Aerial Imagery, Pan or V	12 hours	Varies depending aircraft altitude	Pan, V, NIR, MIR, TIR, M	USGS, Commercial	Min
Satellite Imagery					
Quickbird	1-5 days (depends on latitude)	0.61, 2.5	Pan, M	NIMA	Min
IKONOS	2-3 days	1, 4	Pan, M	NIMA	Min
OrbView-3,4	< 3 days	1, 4	Pan, M	NIMA	Min
SPIN-2.	45 days	2, 10	Pan(panoramic), Pan	NIMA	Min
SPOT-1,2,3,4	26 days (1 day with 3 satellites)	10, 20	Pan, M	NIMA	Min
SPOT 5	< 3 days (1 day with 3 satellites)	2.5, 5, 10	Pan, Pan, M,	NIMA possible, SPOT Image (http://www.spot.com)	Min
Landsat-1,2,3 MSS	18 days	56x79	M	NIMA	Min
Landsat-4,5 MSS and TM	16 days	30, 56x79, 120	M, M, TIR (has two multispectral scanners, Thematic Mapper and MSS)	NIMA	Min
Landsat-7 ETM+	16 days	15, 30, 60	Pan, M, TIR	NIMA possible, USGS (http://landsat7.usgs.gov/index.php)	Min

IRS-1 AB	22 days (11 days with both satellites)	36.25, 72.5	M, M	Space Imaging, Inc (http://www.spaceimagingme.com/)	High
IRS-1 CD	24 days	5.8, 70, 188, 23.5	Pan, MIR, (R and NIR), M	Space Imaging, Inc (http://www.spaceimagingme.com/)	High
IRS-P5	Searching for temporal	2.5	Pan	Space Imaging, Inc (http://www.spaceimagingme.com/)	High
ASTER	4 to 16 days	15, 30, 90	V, NIR, MIR; NIR, MIR; TIR	NASA Earth Observing System (EOS) Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/)	Min
Multi-spectral Aerial Imagery					
Daedalus(aerial)	On Demand weather permitting	2.5 at 1000 m AGL	M including TIR band	NIMA possible (http://www.spatial.maine.edu/~tony/ICIP01Pete.PDF), Commercial companies	High
ATLAS(aerial)	On Demand weather permitting	2.5 at 6000 ft AGL	M including TIR band	NASA Stennis Space Center (http://wwwghcc.msfc.nasa.gov/precisionag/atlasremote.html)	Min
Radar					
SIR-A	2.5 days only in 1978	40x40	L-band Radar	NASA Earth Observing System (EOS) Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/)	Min
SIR-B	8 days only in 1984	17x25	L-band Radar	NASA Earth Observing System (EOS) Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/)	Min

SIR-C	10 days only in 1994	10-30x 30	X, C, and L-band Radar	NASA Earth Observing System (EOS) Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/)	Min
JERS-1	From 1992 to 1998	18x24, 18x18	M, L-band Radar	NIMA	Min
Almaz-1	From 1991 for 18 months	15 x 15-30	S-band Radar	Not clear where to obtain (http://www.hobbyspace.com/SatEyes/#SpysatImages)	Medium
RADARSAT-1	From 1995 to present, 24 days revisit	10-100x10-100	C-band Radar	NIMA (RADARSAT-1)	Min
ERS-1,2.	From 1991/1995 to present	30x26	C-band Radar	NIMA	Min
STAR 3i	Presently in operation	3x3	X-band Radar	NIMA, Intermap (http://www.intermaptechnologies.com/intermap_home_page.htm)	Min
LiDAR					
LiDAR	12 hours	0.2 horizontal, 0.1 vertical	L (Laser)	Private	High
1. Imagery System	**2. Revisit Temporal Resolution**	**3. Spatial Resolution(km)**	**4. Spectral Resolution**	**5. Availability**	**6. Cost(Qualitative)**
Satellite Imagery-Low Resolution					
MODIS		.250 to 1 (Jensen,			
SPOT-4 Veg		1			
OrbView-2 SeaWiFS		1.13		NIMA	Min
AVHRR	24 hours (Jensen, 2000:205)	1.1, 4	M, M with resampling for higher frequency		
GOES	15 minutes U.S. (Jensen, 2000:203)	1, 4, 8	VIS, TIR, TIR		
METEOSAT					
NWS WSR-88D					

Appendix D: Final Imagery System Key

This appendix contains the final imagery system key. The matrix has eight columns of data to help decision-makers with detailed capabilities about each imagery system outlined in the thesis. A more detailed discussion of each column is in Chapter 4.

Jensen's textbook, Jensen and Cowen's journal article, and a NIMA document were used as references for the imagery decision matrix and imagery system key. They are as follows:

Jensen, John R. *Remote Sensing of the Environment An Earth Resource Perspective*. Upper Saddle River, New Jersey: Prentice-Hall Inc., 2000.

Jensen, John R. and Dave C. Cowen, "Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*," *Photogrammetric Engineering & Remote Sensing,* 65: 611-622 (May 1999).

"Status of Selected Current & Future Commercial Remote Sensing Satellites." National Geospatial Intelligence School, NIMA. Handout from a seminar. 24 June 2002.

Table 2.

Imagery System Key	Pan=Black and white panchromatic(0.5-0.7μm)
SPECTRAL LEGEND:	V=visible color(0.4-0.7μm)
	B=Blue (0.4-0.5μm)
	G=Green (0.5-0.6μm)
	R=Red (0.6-0.7μm)
	NIR=Near-infrared including black and white infrared, color infrared (0.7-1.1μm)
	MIR=Mid-infrared including black and white infrared, color infrared(1.5-2.5μm)
	TIR=Thermal infrared(3-12μm)
	M=Multi-spectral (Includes V, NIR,MIR, and depending on sensor; TIR)
	L=Light Detection and Ranging (LiDAR)
	Note: LiDAR is used mainly for elevation data; an additional imagery system such as Pan is used to meet the requirements of the mission
	Radar=Aerial or satellite Radar
	Note: Items in italics are above the minimum spectral resolution requirement, however, the imagery system chosen must also meet the minimum temporal and spatial resolution. Where Multispectral is not used in the table, it is not needed for the requiremen

1. Imagery Category-Range 1 to 4 (low to high)	2. Imagery System	3. Temporal Resolution	4. Spatial Resolution (m)	5. Spectral Resolution	6. Availability	7. Cost(Qualitative)	8. General Use
	Aerial Imagery						
4	Aerial Imagery	On Demand weather permitting	Depends on aircraft altitude	Pan, V, NIR, MIR, TIR, M	USGS, Commercial	Low, High	Precision measurements and analysis
3 or 4 depends on altitude	Daedalus(aerial)	On Demand weather permitting	2.5 at 1000 m AGL	M (8 bands from UV to NIR, and 2 TIR bands)	NIMA possible (http://www.spatial.maine.edu)	Low, High	Precision measurements and analysis
3 or 4 depends on altitude	ATLAS(aerial)	On Demand weather permitting	2.5 at 6000 ft AGL	M (6 bands in V and NIR, 2 MIR, 6 TIR)	NASA Stennis Space Center(http://wwwghcc.msfc.nasa.gov)	Med	Precision measurements and analysis
4	LiDAR	On Demand weather	0.2 horizontal, 0.1 vertical	L (Laser)	Commercial	High	Precision measurements and analysis

	Satellite Imagery						
4	Quickbird	1-5 days (depends on	0.61	Pan	NIMA	Min	Precision measurements and analysis
3	Quickbird	1-5 days (depends on	2.5	M (B, G, R, NIR)	NIMA	Min	Local multispectral analysis
4	IKONOS	2-3 days	1	Pan	NIMA	Min	Precision measurements and analysis
3	IKONOS	2-3 days	4	M (B, G, R, NIR)	NIMA	Min	Local multispectral analysis
4	OrbView-3,4	< 3 days	1	Pan	NIMA	Min	Precision measurements and analysis
3	OrbView-3,4	< 3 days	4	M (B, G, R, NIR)	NIMA	Min	Local multispectral analysis
3	SPIN-2.	45 days	2	Pan(panoramic)	NIMA	Min	Precision measurements and analysis
2	SPIN-2.	45 days	10	Pan	NIMA	Min	Local analysis
2	SPOT-1,2,3	26 days (1 day with 3 satellites)	10	Pan	NIMA	Min	Local analysis
2	SPOT-1,2,3	26 days (1 day with 3 satellites)	20	M (G, R, NIR)	NIMA	Min	Regional multispectral analysis
2	SPOT-4	26 days (1 day with 3 satellites)	10	Pan	NIMA	Min	Local analysis
2	SPOT-4	26 days (1 day with 3 satellites)	20	M (G, R, NIR, MIR)	NIMA	Min	Regional multispectral analysis
3	SPOT 5	< 3 days (1 day with 3 satellites)	2.5	Pan	NIMA possible, SPOT Image (http://www.spot.com)	Min, High	Local analysis
3	SPOT 5	< 3 days (1 day with 3 satellites)	5	Pan	NIMA	Min	Local analysis
2	SPOT 5	< 3 days (1 day with 3 satellites)	10	M (G, R, NIR, MIR)	NIMA	Min	Local multispectral analysis
1	Landsat-1,2,3 MSS	18 days	56x79	M (G, R, NIR, NIR)	NIMA	Min	Regional multispectral analysis
1	Landsat-1,2,3 MSS	18 days	240	TIR	NIMA	Min	Regional thermal analysis
1	Landsat-4,5 MSS	16 days	56x79	M (G, R, NIR, NIR)	NIMA	Min	Regional multispectral analysis
1	Landsat-4,5 TM	16 days	30	M (B, G, R, NIR, MIR, MIR)	NIMA	Min	Regional multispectral analysis
1	Landsat-4,5 TM	16 days	120	TIR	NIMA	Min	Regional thermal analysis

2	Landsat-7 ETM+	16 days	15	Pan	NIMA possible, USGS (http://landsat7.usgs.gov/index.php)	Min, Min	Local analysis
1	Landsat-7 ETM+	16 days	30	M (B, G, R, NIR, MIR, MIR)			Regional multispectral analysis
1	Landsat-7 ETM+	16 days	60	TIR			Regional thermal analysis
1	IRS-1 AB	22 days (11 days with both satellites)	36.25	M (B, G, R, NIR)	Space Imaging, Inc (http://www.spaceimagingme.com/)	High	Regional multispectral analysis
1	IRS-1 AB	22 days (11 days with both satellites)	72.5	M (B, G, R, NIR)			Regional multispectral analysis
3	IRS-1 CD	24 days	5.8	Pan	Space Imaging, Inc (http://www.spaceimagingme.com/)	High	Local analysis
1	IRS-1 CD	24 days	188	R, NIR			Regional multispectral analysis
2	IRS-1 CD	24 days	23.5	M (G, R, NIR)			Regional multispectral analysis
1	IRS-1 CD	24 days	70	MIR			Regional thermal analysis
3	IRS-P5	To be determined	2.5	Pan	Space Imaging, Inc (http://www.spaceimagingme.com/)	High	Local analysis
2	ASTER	4 to 16 days	15	M (G, R, NIR, NIR)	NASA Earth Observing System (EOS) Gateway(http://edcimswww.cr.usgs.gov)	Min	Local multispectral analysis
1	ASTER	4 to 16 days	30	6 NIR to MIR bands			Regional multispectral analysis
1	ASTER	4 to 16 days	90	5 TIR bands			Regional thermal analysis
2	JERS-1	From 1992 to 1998	18	M (G, R, 2 NIR, 4 MIR)	NIMA	Min	Regional analysis
	Radar						
1	SIR-A	2.5 days only in 1978	40 x 40	L-band Radar	NASA Earth Observing System (EOS) Gateway(http://edcimswww.cr.usgs.gov)	Min	Regional analysis
1	SIR-B	8 days only in 1984	17 x 25	L-band Radar	NASA Earth Observing System (EOS) Gateway(http://edcimswww.cr.usgs.gov)	Min	Regional analysis

1	SIR-C	10 days only in 1994	10-30 x 30	X, C, and L-band Radar	NASA Earth Observing System (EOS) Gateway (http://edcimswww.cr.usgs.gov)	Min	Regional analysis
2	JERS-1	From 1992 to 1998	18	L-band Radar	NIMA	Min	Regional analysis
2	Almaz-1	From 1991 for 18 months	15x15-30	S-band Radar	(http://www.hobbyspace.com/SatEyes/#SpysatImages)	Med	Regional analysis
1	RADARSAT-1	From 1995 to present, 24 days	10-100x10-100	C-band Radar	NIMA (RADARSAT-1)	Min	Regional analysis
1	ERS-1,2.	From 1991/1995 to present	30x26	C-band Radar	NIMA	Min	Regional analysis
3	STAR 3i	Presently in operation	3x3	X-band Radar	NIMA, Intermap (http://www.intermaptechnologies.com/intermap_home_page.htm)	Min	Local analysis

Appendix E: Instruction Sheet

Instruction Sheet for Using the Imagery Decision Matrix and the Imagery System Key

Table 1-Imagery Decision Matrix

The Imagery Decision Matrix is used to determine what type(s) of remote sensing imagery are applicable for a specific Air Force requirement. The electromagnetic spectrum used in remote sensing consists of wavelengths from ultraviolet light to microwaves (Radar). Remote sensing makes use of these wavelengths to produce images.

The following columns are used in the matrix:

1. Applications Air Force applications that were identified through a review of current literature, an Air Force Geo-Integration Office (AF/GIO) survey of 85 CONUS bases, and a 2002 Geospatial Technologies Symposium & Exposition. The matrix can be used to determine the imagery that best suits an application or as an educational tool to learn about the imagery types and capabilities that are available. Many potential applications are identified in Column 1 of the matrix. Applications are organized according to classification areas such as Urban or built-up land, Agriculture, Rangeland, Forest Land, Water, Wetland, and Multiple.

2. Temporal Resolution Identifies the amount of time that imagery data can be used before a refresh of imagery is suggested. This takes into account the timeliness of the imagery for a given application. For instance, if you want distance and area measurements, the imagery should be updated every one to five years at a minimum.

3. Spatial Resolution The minimum spatial resolution that is necessary for an analyst to see a particular level of detail and distinguish earth features of interest for a particular application. For instance, a 1 x 1 meter spatial resolution image will allow an analyst to determine information about features that are 2 x 2 meter in size or larger. Each 1 x 1 meter square is called a pixel. A minimum of two pixels wide in the x-direction and two pixels wide in the y-direction (or 4 pixels) is required to determine information about features of interest.

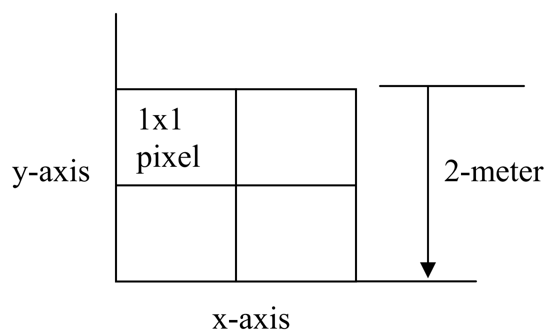


Figure E-1: Spatial Resolution of Features

4. Spectral Resolution Spectral resolution allows an analyst to determine information from an image based on spectral reflectance of features. Various parts of the electromagnetic spectrum that an imagery system may 'see' include ultraviolet; visible green, blue, and red; near infrared; mid-infrared; thermal infrared; radar; and laser. The spectral resolution capability of each remote sensing system varies. For example, the sensor onboard the Quickbird satellite can 'see' ultraviolet; visible green, blue, and red; near-infrared, and mid-infrared wavelengths of the electromagnetic spectrum. Quickbird uses these wavelengths to produce imagery.

5. Imagery Systems Each application receives a category code corresponding to the imagery that will be useful. Imagery systems are identified further in Table 2, the imagery system key, with appropriate category code, capabilities, availability, cost, and general use.

Table 2-Imagery System Key

The imagery system key provides further information about the imagery systems that fulfill requirements of each application. At the top of the key, the spectral legend identifies the meaning of acronyms used in the imagery decision matrix and imagery system key. The wavelengths of each section of the electromagnetic spectrum are identified. For instance, Pan=Black and white panchromatic (0.5-0.7 μm). This means that black and white panchromatic collects information on the electromagnetic spectrum using 0.5-0.7 μm wavelengths. Characteristics of each imagery system are listed as opposed to the minimum imagery requirements identified in the matrix. Columns included are imagery category, imagery system, temporal resolution, spatial resolution, spectral resolution, availability of imagery, qualitative cost, and general uses. A description of each follows:

1. Imagery Category- Range 1 to 4 (low to high) Capability Each imagery system is categorized according to the capability of the imagery. The rank is based on spatial resolution. A category 1 imagery system provides the least spatial resolution, while a category 4 imagery system has the best spatial resolution.

2. Imagery System The name of each imagery system is identified.

3. Temporal Resolution (hours or days) Identifies the frequency of obtaining imagery covering a specific geographic area, weather permitting. With the exception of Radar and LiDAR, all of the imagery systems require non-cloudy conditions to obtain imagery. LiDAR may be collected in cloudy conditions only if the aerial platform (airplane or helicopter) can fly beneath the cloud-covered area. For satellite imagery, a satellite is on a predetermined orbiting path and imagery is available at a set time such as every two days at best for IKONOS. The temporal resolution is the highest frequency possible if a user has requested imagery of the same geographic area each time the satellite orbits overhead. A satellite has a wide field of view, however only a portion of the geographic area is imaged depending on the spatial resolution of the satellite and user requests. For aerial imagery, the amount of time required to obtain the first set of imagery on demand will vary. Once the first fly-over is coordinated, the frequency of obtaining imagery should be a relatively short period of time such as 12 hours or less.

4. Spatial Resolution (meters) The spatial resolution is the level of detail an imagery system can record. For instance, IKONOS 1-meter spatial resolution is higher than IKONOS 4-meter spatial resolution. The 1-meter IKONOS will have 16 pixels covering a 4x4 meter area. The 4-meter IKONOS will have 1 pixel covering the same 4x4 meter area.

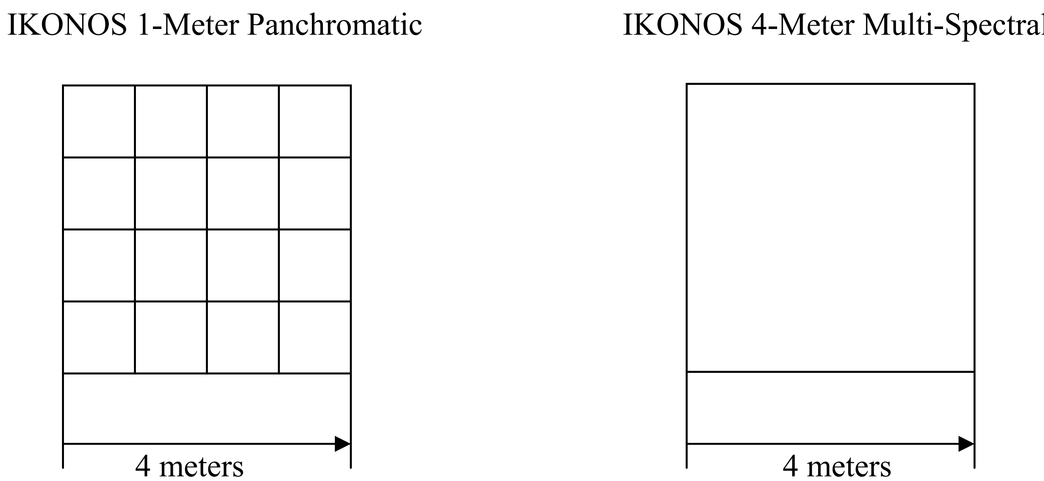


Figure E-2: Spatial Resolution of Imagery System

5. Spectral Resolution (spectral bands) The spectral resolution of an imagery system may provide imagery that uses one or more of the ultraviolet, red, green, blue, near-infrared, mid-infrared, thermal infrared, and radar wavelengths. Most imagery systems have more than one subsystem that can record electromagnetic energy to produce an image. For example, Quickbird has two imaging subsystems. The imagery available from Quickbird is 0.61-meter panchromatic imagery and 2.5 meter multi-spectral imagery.

6. Availability Suggested sources on where to find the imagery through government or commercial sources. Each source should be investigated to determine the extent of imagery products available. Issues of formatting and availability for a particular area have to be determined on a case-by-case basis.

7. Cost (Qualitative) The qualitative cost of imagery. Minimal costs take into account fees associated with mailing and miscellaneous fees. Low cost refers to less than

$2000 per image, while medium and high costs refer to $2000 to $5000, and above $5000 respectively. The cost of imagery will vary depending on the format. Formats, for example, are digital, hard copy, or downloaded through an Internet site.

8. General Use Imagery systems are grouped according to researcher-defined geographic area coverage: precision, local, or regional. These are qualitative measures that indicate how the imagery system can be used. Precision denotes the highest spatial resolution of <2 meters and would allow decisions to be made about a single base facility. Local represents a resolution of 2-15 meters, displaying a broader view of an Air Force base. Regional, with the least spatial resolution capability, >15 meters, would encompass an area as large as a county or state. Multi-spectral and thermal analysis is pointed out for imagery systems with this capability.

How to use the Imagery Decision Matrix and Imagery System Key:

1. Starting with the imagery decision matrix, identify what your required application is such as distance and area measurements, habitat modeling, and facility elevations in Column 1.
2. The minimum temporal, spatial, and spectral resolution is given in Columns 2 through 4. (See the spectral legend in the imagery system key for explanation of spectral acronyms). If your application is not represented, some interpolation may be made to determine imagery useful for your application.
3. The imagery system, Column 5, will identify the appropriate category code required to meet the needs of each specific application. Categories identified here are the same categories identified in Column 1 of Table 2. Each user will

need to determine the best imagery system for each application. Note that imagery categories range from 1 to 4, lowest to highest spatial resolution.

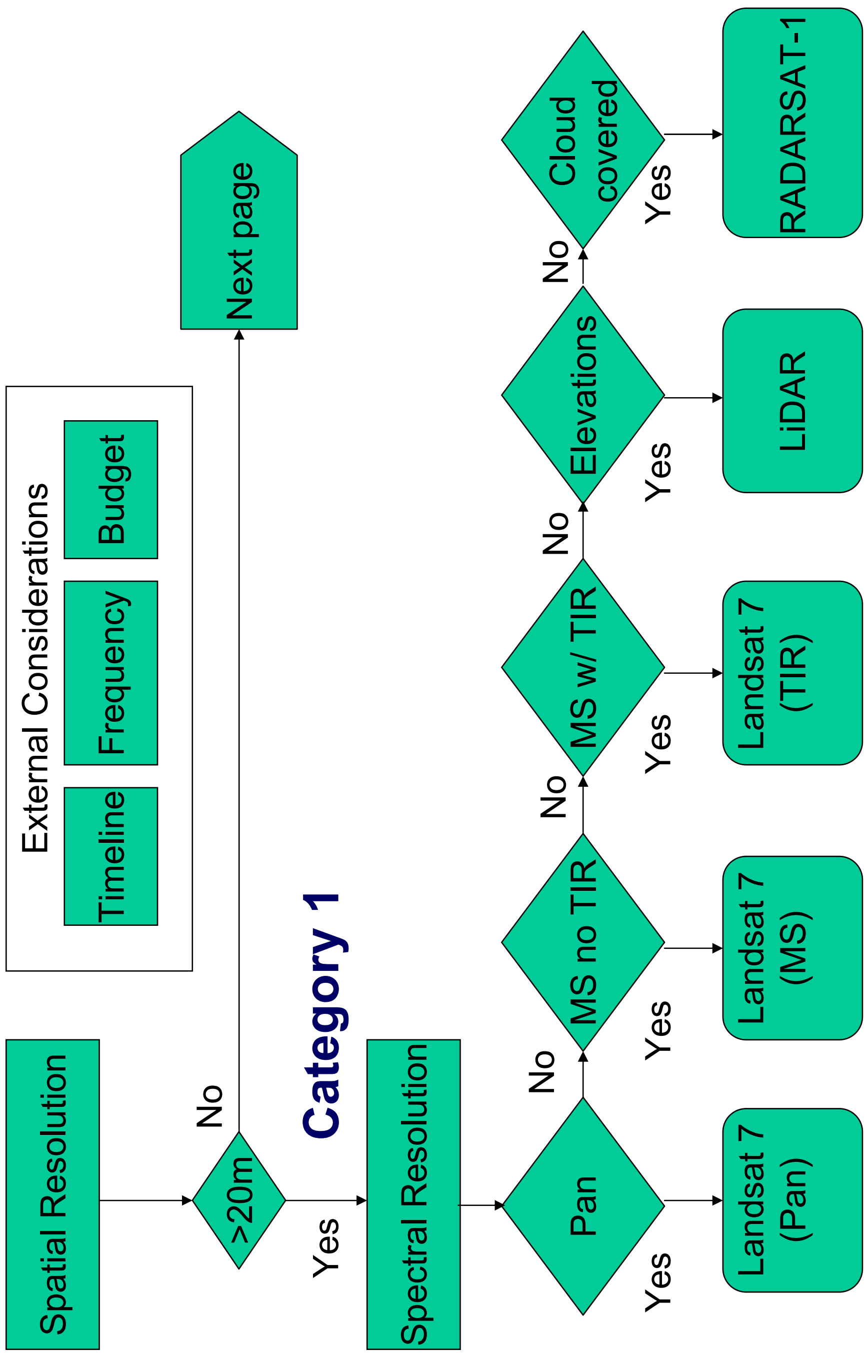
4. Table 2, the imagery system key, has information on the category code, temporal resolution, spatial resolution, spectral resolution, availability, qualitative cost, and general use designation for each imagery system.

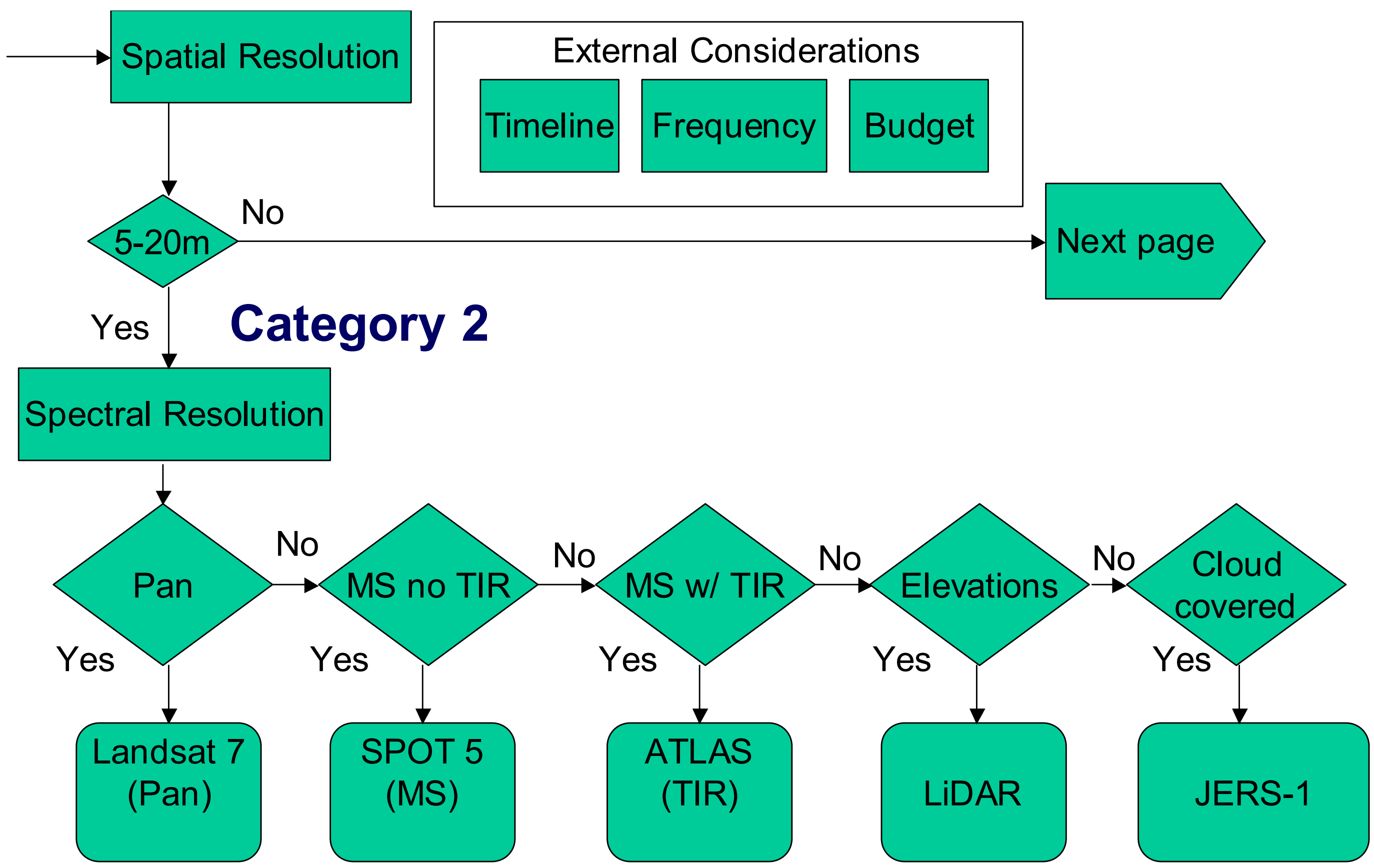
Example:

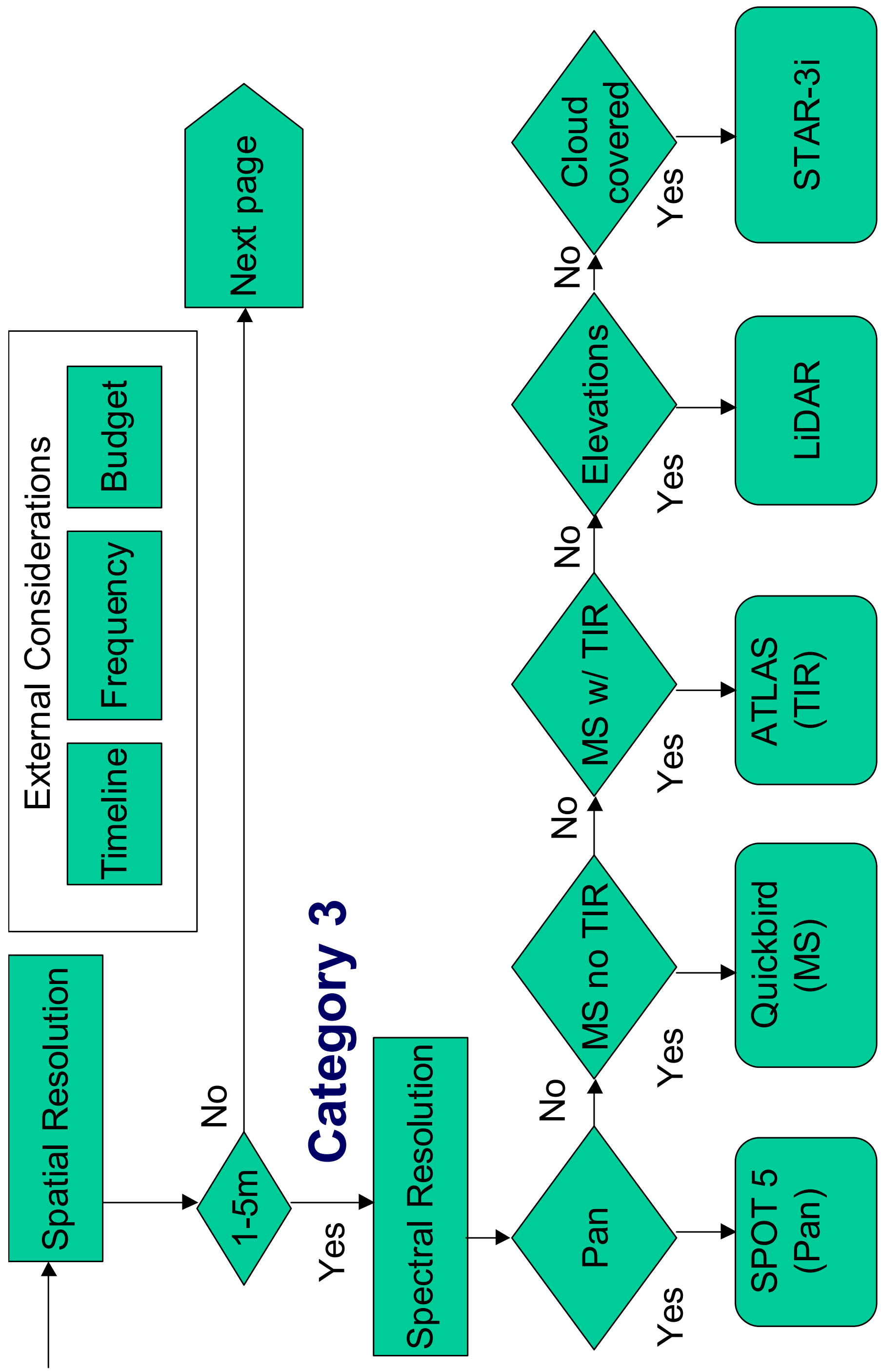
1. You have been tasked to determine buildings on base that may have a problem with excessive heat loss. Your base is also constructing 200 new housing units and would like to make sure that all of them have appropriate insulation upon completion. The units will be constructed over a 2-year time period in phases of 25 units every three months.
2. In Column 1 of the decision matrix, the applications column, you will find building heat loss identification represented.
3. Note the corresponding information about your application in Column 2 (temporal resolution), Column 3 (spatial resolution), and Column 4 (spectral resolution). The data in these columns is 1-5 years, 1-5 meters, and TIR respectively. (See the spectral legend in the imagery system key for explanation of spectral acronyms). Depending on your specific project, you may have stricter requirements for each of the resolutions. For your project, you are constructing 200 new family housing units in 8 phases beginning every 3 months. Your dynamic situation requires a higher temporal resolution. You may want to obtain imagery every three months instead of every one to five years.

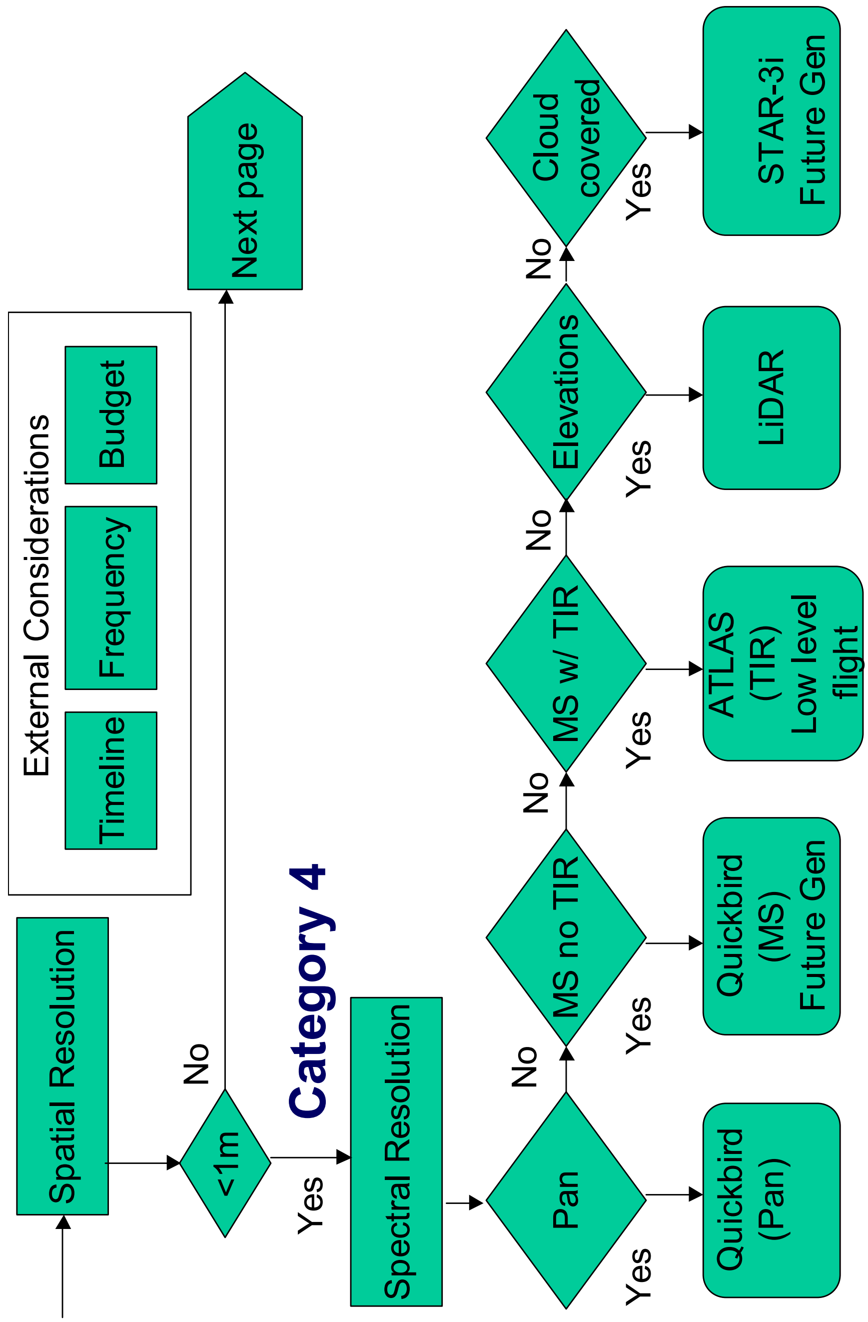
4. If your resolution requirements are met, Column 5 (imagery systems) will identify the appropriate imagery category for building heat loss. Category 3 is designated for this application.
5. Refer to Table 2, Column 1 of the imagery system key, and determine an imagery system of category 3 or higher with thermal infrared capability. (Remember that the category codes account only for the spatial resolution.) The imagery systems that will meet your requirements are Daedalus (aerial and ATLAS (aerial). You can determine the one that best meets your needs based on cost and availability. Suppose you choose ATLAS. Your next goal will be to obtain on-demand thermal-infrared aerial imagery every three months. However, due to the expense of obtaining on-demand imagery, you may want to wait until the project is completed (instead of requesting imagery for every three-month construction phase) to request a thermal infrared imagery fly-over. Additional information on the temporal resolution, spatial resolution, spectral resolution, availability, qualitative cost, and general use are also provided. Note that as imagery becomes more widely used, and more competition develops, the cost of imagery may be reduced.

Appendix F: Imagery Decision Flowchart




Spatial Resolution
External Considerations
Timeline
Frequency
Budget
5-20m
No
Next page
Yes
Category 2
Spectral Resolution
Pan
No
MS no TIR
No
MS w/ TIR
No
Elevations
No
Cloud covered
Yes
Yes
Yes
Yes
Yes
Landsat 7 (Pan)
SPOT 5 (MS)
ATLAS (TIR)
LiDAR
JERS-1


Spatial Resolution
1-5m
No
Yes
Next page
External Considerations
Timeline
Frequency
Budget
Category 3
Spectral Resolution
Pan
MS no TIR
MS w/ TIR
Elevations
Cloud covered
Yes
No
SPOT 5 (Pan)
Quickbird (MS)
ATLAS (TIR)
LiDAR
STAR-3i


Spatial Resolution
External Considerations
Timeline
Frequency
Budget
<1m
Yes
No
Next page
Category 4
Spectral Resolution
Pan
Yes
No
Quickbird
(Pan)
MS no TIR
Yes
No
Quickbird
(MS)
Future Gen
MS w/ TIR
Yes
No
ATLAS
(TIR)
Low level
flight
Elevations
Yes
No
LiDAR
Cloud
covered
Yes
STAR-3i
Future Gen

List of Symbols, Abbreviations and Acronyms

AAA	Anti-Aircraft Artillery
AFB	Air Force Base
AF/GIO	Air Force Geo-Integration Office
AFMC	Air Force Materiel Command
AGL	Above Ground Level
Almaz-1	Russian SAR Imagery, meaning diamond
ASC	Aeronautical Systems Center
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer. Multi-spectral sensor on the NASA TERRA satellite.
ATLAS	Advanced Thermal and Land Applications Sensor. Also referred to as Airborne Terrestrial Applications Sensor. NASA Multi-spectral airborne sensor.
AVHRR	Advanced Very High Resolution Radiometer
BAM	Bird Avoidance Model
CAD	Computer-Aided Drawing
CIA	Central Intelligence Agency
CIP	Common Installation Picture
CONUS	Continental United States
CSIL	Commercial Satellite Imagery Library
DIA	Defense Intelligence Agency
DoD	Department of Defense
DoDD	Department of Defense Directive
DOE	Department of Energy
DOQ	Digital Orthophoto Quadrangle
DRU	Direct Reporting Unit
DVD-R	Digital Versatile Disc Recordable
EOS	Earth Observing System
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Systems Data Center
ERS-1, 2	European Space Agency Radar
ESRI	Environmental Systems Research Institute, Inc.
FBI	Federal Bureau of Investigation
FTP	File Transfer Protocol
GB	Gigabytes-Equal to 1,024 Megabytes
GHz	Gig Hertz, Computer processing speed
GIO	Geo-Integration Office/Officer
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite
GWAC	Government Wide Agency Contract
ID/IQ	Indefinite Delivery/Indefinite Quantity
IKONOS	Greek word for image. American Remote Sensing Satellite
IRS	Indian Remote Sensing Satellite

IT	Information Technology
JERS-1	Japanese Environmental Remote Sensing Radar
Landsat ETM+	Land Satellite Enhanced Thematic Mapper Plus
Landsat MSS	Land Satellite Multi-spectral Scanner
Landsat TM	Land Satellite Thematic Mapper
LiDAR	Light Detection and Ranging
M	Multi-spectral
MAJCOM	Major Command
METEOSAT	Meteorological Satellite
Min	Minimum
MIR	Mid-Infrared
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Minimum Operating Strip
MSS	Multi-spectral Scanner
NAIC	National Air Intelligence Center
NASA	National Aeronautics and Space Administration
NIMA	National Imagery and Mapping Agency
NIR	Near-Infrared
NOAA	National Oceanic and Atmospheric Administration
NRO	National Reconnaissance Office
NSA	National Security Agency
NWS WSR-88D	National Weather Service, Weather Surveillance Radar 88 Doppler
OrbView	Multi-spectral Satellite Named derived from the ORBIMAGE company.
PACAF	Pacific Air Forces
Pan	Panchromatic
RADAR	Radio Detection and Ranging
RAM	Random-Access Memory
RRR	Rapid Runway Repair
SAIC	Science Applications International Corporation
SAM	Surface-To-Air Missile
SAR	Synthetic Aperture Radar. Transmits microwaves.
SCS	Soil Conservation Service
SEAWIFS	Sea-viewing Wide-Field of view Sensor
SIPRNET	Secret Internet Protocol Router Network
SIR-A, B, C	Shuttle Imaging Radar. U.S. Space Shuttle
SPIN-2	Space Information-2 meter. Russian satellite imagery.
SPOT	Systeme Probatoire d'Observation de la Terre. French multi-spectral satellite.
STAR-3*i*	Commercial Satellite Radar
TBMCS	Theater Battle Management Core System
TERRA	Latin for land. NASA's Earth Observing System flagship satellite. Multi-spectral.
TIR	Thermal Infrared
μm	Micrometer. Equal to 1 x 10 ^(-6) meter
USAF	United States Air Force

USAFA	United States Air Force Academy
USDA	United States Department of Agriculture
USDA-ASCS	United States Department of Agriculture-Agricultural Stabilization and Conservation Service
USFS	United States Forest Service
USGS	United States Geological Survey
UV	Ultraviolet
UXO	Unexploded Ordnance
V	Visible
VFT	Value-Focused Thinking
WSR	Weather Surveillance Radar

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Vita

Captain Steve J. Paylor graduated from Buckeye Central High School in New Washington, Ohio. He attended Ohio State University in Columbus, Ohio where he graduated with a Bachelor of Science degree in Civil Engineering with a specialization in Remote Sensing in December 1995. He was commissioned through Officer Training School (OTS), Maxwell AFB, Alabama, in May 1997. Following OTS, Captain Paylor was assigned to Goodfellow AFB, Texas for intelligence career-field training. In April 1998, he attended the Army's Defense Mapping School at Fort Belvoir, Virginia, to study mapping, charting, and geodesy. In June 1998, he reported to the 27th Operational Support Squadron at Cannon AFB, New Mexico, where he served as Chief of Intelligence, Readiness. Captain Paylor also served as Chief of Operational Intelligence at Cannon's 523 Fighter Squadron.

Captain Paylor cross-trained into the Civil Engineering career-field while stationed at Cannon AFB. In December 1999, he began service as a Civil Engineer for the 27th Civil Engineer Squadron. He graduated from the Base Civil Engineer Organization Course at the Air Force Institute of Technology (AFIT) in September 2000. In December 2000, he served as Chief of SABER (Simplified Acquisition of Base Engineering Requirements). Captain Paylor began his master's studies in August 2001 at the AFIT Graduate School of Engineering. Upon graduation, he will serve as Civil Engineering Flight Commander, Logistics Support Squadron, 33rd Fighter Wing, Eglin AFB, Florida.

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14. ABSTRACT

The U.S. Air Force is implementing GeoBase, a geographic information system (GIS), throughout its worldwide installations. Air Force GIS needs can be augmented by aerial and satellite imagery. Imagery improvements over the past several years will significantly increase GeoBase usefulness in a range of mission requirements. Potential Air Force uses of imagery include identifying heat loss, environmental monitoring, command decision-making, and emergency response. A decision tool was developed to determine the appropriate imagery for Air Force Applications. Literature review and a 2002 Air Force Geo-Integration Office (AF/GIO) survey were used to develop a comprehensive imagery applications list that satisfies Air Force mission requirements. An imagery decision matrix allows users to select an application and find imagery that fulfills requirements. An imagery system key provides further details of each imagery type. Three Air Force bases validated the matrix. Increased awareness of an imagery-enriched GeoBase and efficiency afforded by the matrix, greatly reduces the time to identify and implement imagery. Available imagery was identified for the three Air Force bases at the National Imagery and Mapping Agency (NIMA) through a government contract at no additional cost. Current IKONOS imagery of Elmendorf Air Force base was obtained for analysis and implementation into GeoBase.

15. SUBJECT TERMS

Remote Systems, Satellite Imagery, Aerial Imagery, GeoBase, Geographical Information Systems

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